

PROCESS FOR MANUFACTURING AN α -DIHYDROXY DERIVATIVE AND
EPOXY RESINS PREPARED THEREFROM

Background of the Invention

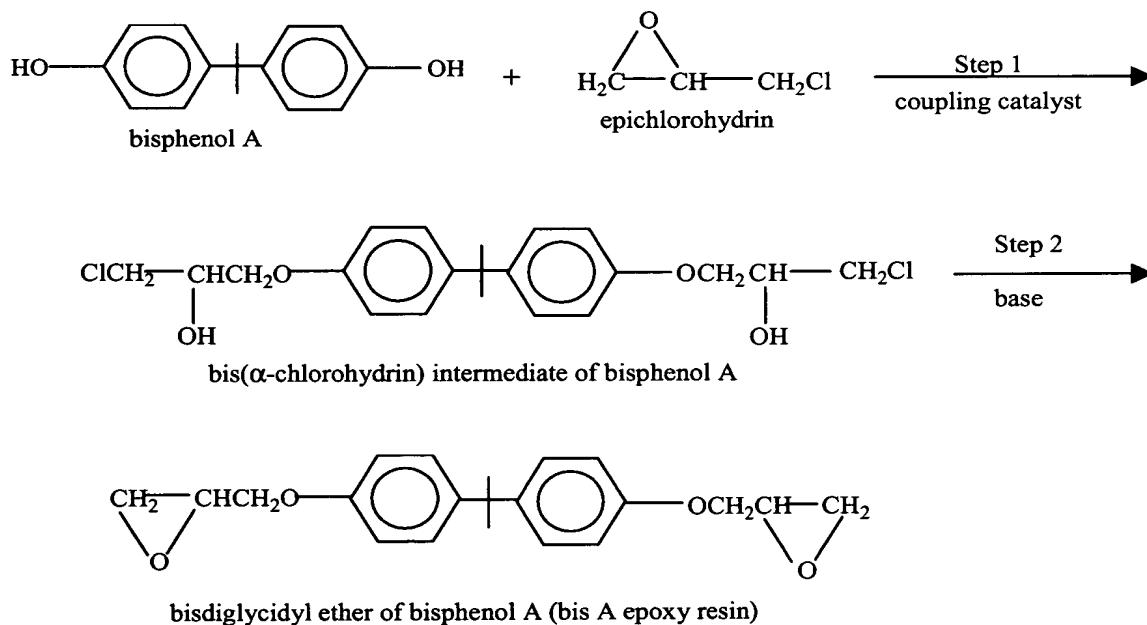
The present invention relates to a process for
5 manufacturing an α -dihydroxy derivative from an aryl allyl
ether and converting such α -dihydroxy derivative to an
epoxy resin. The α -dihydroxy derivative may optionally be
used to produce an α -halohydrin intermediate which, in
turn, is used to make an epoxy resin. For example, the
10 process of the present invention is useful for
manufacturing a bisphenol A (bis A) epoxy resin.

In a well-known industrial process for producing
epoxy resins on a large commercial scale, in a first step,
an α -halohydrin, as a reactive intermediate, is made by
15 reacting an active hydrogen-containing compound such as an
alcohol, a phenol, a carboxylic acid or an amine with an
epoxide-containing epihalohydrin, such as epichlorohydrin
(ECH) or epibromohydrin. In this first step, the epoxide
moiety of the epihalohydrin is consumed in the formation
20 of the α -halohydrin moiety. Then, in a second step, the
 α -halohydrin moiety is converted back into an epoxide
moiety of a glycidyl ether, glycidyl ester, or glycidyl
amine under basic reaction conditions.

The most widely made and particularly useful
25 epoxy resin is bis A epoxy resin which is made by the
coupling reaction of bis A and ECH through the epoxy
moiety of ECH to form the bis(α -chlorohydrin) intermediate
in a first step. Then, in a dehydrochlorination reaction
with base in which an epoxide moiety is reformed, as a

second step, the bis A bis(α -chlorohydrin) intermediate is converted to the bis A diglycidyl ether epoxy resin. Such a two-step process for making an epoxy resin is described by H. Lee and K. Neville in "Handbook of Epoxy Resins",
 5 McGraw-Hill Book Co., New York, New York, 1982, Reissue,
 2-3 to 2-4. This process is shown in the following reaction sequence, Reaction Sequence (I). More specifically, Reaction Sequence (I) shows a process chemistry scheme for a two-step, industrial manufacture of
 10 bis A epoxy resin via the reaction of bis A and ECH to make a chlorohydrin intermediate.

Reaction Sequence (I)



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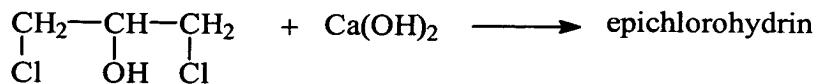
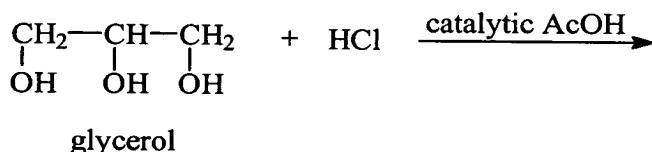
bisdiglycidyl ether of bisphenol A (bis A epoxy resin)

The above two-step process of coupling bis A and ECH by reaction at the epoxide ring followed by epoxide ring-forming dehydrochlorination has also been combined into a single-step reaction, wherein the bis(α -chlorohydrin) intermediate of bis A is generated *in situ* and converted into an epoxy simultaneously. Such a
 20

single-step process for making bis A epoxy resin is described in U.S. Patent Nos. 4,499,255; 4,778,863; and 5,028,686.

Another method to generate α -chlorohydrins, as reactive intermediates, that does not consume an epoxide moiety of any of the reactants, is described in U.S. Patent No. 2,144,612 in which glycerol, which is an α -dihydroxy derivative, is converted into an α -chlorohydrin by reaction with anhydrous hydrogen chloride (HCl) in the presence of a catalytic amount of acetic acid (AcOH). U.S. Patent No. 2,144,612 describes a process that is shown in the following reaction sequence, Reaction Sequence (II), for making glycerol dichlorohydrin, a precursor for epichlorohydrin from the α -dihydroxy derivative glycerol. More specifically, Reaction Sequence (II) shows chemistry for epichlorohydrin synthesis via the reaction of glycerol with hydrogen chloride and acetic acid to make glycerol dichlorohydrin.

Reaction Sequence (II)



20 glycerol chlorohydrin

Although ECH is an important commercial product for making α -chlorohydrin intermediates, and particularly

for making the bis A bis(α -chlorohydrin) intermediate precursors of bis A epoxy resin, ECH provides a chlorine-intensive route to producing epoxy resins. In the predominate commercial process for making ECH, ECH is made from allyl chloride, which in turn, is made from thermal chlorination of propylene using chlorine gas, a process that produces chlorinated by-products. Generally, chlorinated by-products are treated as waste material.

Additionally, a large amount of water is used when converting allyl chloride into an α -chlorohydrin intermediate and then converting the α -chlorohydrin to ECH, and this water must eventually also be treated as waste. Therefore, from an environmental standpoint, there is a desire to reduce the consumption of chlorine and to reduce the generation of chlorinated by-products and waste water in the production of epoxy resin.

In addition, epoxy resins made from ECH by either of the previously described two-step or single-step processes, may have a high organic chloride content which may be deemed as undesirable in some applications, for example, in electronic applications.

It is therefore desired to provide a non-epichlorohydrin process for making epoxy resins such as bis A epoxy resin. That is, it is desired to provide an alternative epoxy resin route, i.e., an alternative process without using ECH for manufacturing epoxy resins.

One non-epichlorohydrin process for manufacturing epoxy resins is described in U.S. Patent No. 6,001,945. In the process of U.S. Patent No. 6,001,945, the epoxide moiety of the reactant glycidol is coupled

with bis A to produce an α -dihydroxy derivative, which is subsequently converted to an α -chlorohydrin via reaction with hydrogen chloride and a catalytic amount of acetic acid via the process described in U.S. Patent No.

5 2,144,612. Glycidol is known to be a highly toxic and thermally unstable material tending to explosively self-polymerize. At low temperatures, such as 70 °C, glycidol is unstable and the loss of epoxide content of glycidol is significant. Glycidol self-polymerization diminishes

10 glycidol selectivity and product yield in its reactions, and the glycidol self-polymerization products complicate separation and purification of the desired reaction product. These undesirable properties of glycidol are described in detail by A. Kleemann and R. Wagner in

15 "Glycidol Properties, Reactions, Applications", Dr. Alfred Huthig Verlag, New York, New York, 1981, pp. 48-52. Thus, it is also desirable to develop processes that can manufacture α -halohydrin intermediates as precursors for manufacturing epoxy resins that do not require glycidol as

20 a reactant.

U.S. Patent Application Serial No. 60/205,366 entitled "Process for Manufacturing a Halohydrin Intermediate and Epoxy Resins Prepared Therefrom," filed by Boriack et al., May 18, 2000 (Attorney Docket No. C-
25 60002), discloses a process for manufacturing an α -halohydrin intermediate of at least one or more phenols and utilizing such α -halohydrin intermediate of the least one or more phenols to make an epoxy resin such as bis A epoxy resin. The above patent application is an
30 improvement over U.S. Patent No. 6,001,945 by utilizing a stable glycidyl acetate in the place of a highly unstable

glycidol. However, even both processes above, consume the epoxide group of an epoxide-containing raw material to make an intermediate which must be subsequently re-epoxidized.

5 It is therefore desired to provide a novel, alternative process for manufacturing epoxy resins without the use of glycidol or epichlorohydrin.

Summary of the Invention

The present invention is a new route to an epoxy resin that is significantly more atom efficient than the currently practiced technology. In conventional routes to epoxy resins that proceed through halohydrin intermediates, greater than two moles of halogen (4 atoms of halogen) are required to produce one equivalent of epoxide group. The route of the present invention does not use chlorine to make the epoxy resin, but instead, uses a hydrogen halide. Thus, in the present invention process, only one mole of hydrogen halide (1 atom of halogen) is required to produce one equivalent of epoxide group.

Also, in conventional processes to make epoxy resins, an epoxide-containing raw material, such as epichlorohydrin, is used to make a non-epoxide-containing intermediate which is subsequently reepoxidized. Such a process that consumes the epoxide group of an epoxide-containing raw material to make a second epoxide-containing compound is not atom efficient, utilizes large amounts of energy because formation of epoxide rings is an energy intensive process, and is more complex than the disclosed process. The present process invention, on the

other hand, uses α -dihydroxy derivatives as precursors to make α -halohydrin intermediates for epoxy resins.

One aspect of the present invention is directed to a process for preparing an α -dihydroxy derivative 5 useful for a process for making an α -halohydrin intermediate including oxidizing the carbon-carbon double bond of the allyl groups of an aryl allyl ether compound to form an α -dihydroxy derivative. The process for manufacturing the α -dihydroxy derivative is preferably 10 carried out in the presence of an oxidant alone functioning as the oxidizing agent; or in the presence of an oxidant in combination with a catalyst. Optionally, the oxidation process of the present invention is carried 15 out in the presence of certain additives, co-oxidants, and co-catalysts, or a solvent.

Another aspect of the present invention is directed to a process for preparing an epoxy resin by converting the aforementioned α -dihydroxy derivative to an epoxy resin.

20 Yet another aspect of the present invention is directed to a process for manufacturing an α -halohydrin intermediate using a halide substitution process to convert the α -dihydroxy derivative described above to the α -halohydrin intermediate. The process is preferably 25 carried out under anhydrous conditions with a hydrogen halide such as hydrogen chloride, hydrogen bromide, or hydrogen iodide, as a reactant; and a carboxylic acid, such as acetic acid, present in a catalytic amount or a carboxylic acid ester, such as 1-methoxy-2-propanol

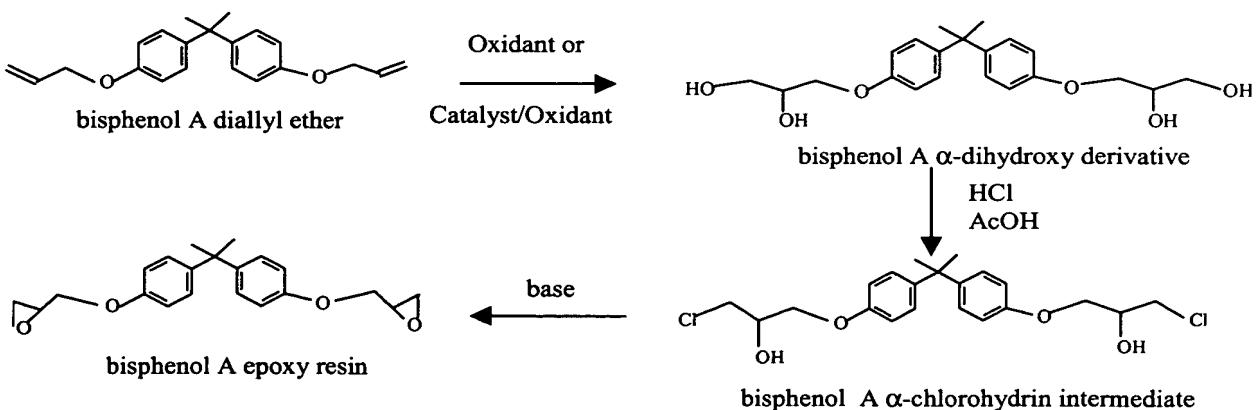
acetate, present in a catalytic amount, or present as a solvent; and optionally, the process is carried out in the presence of a non-carboxylic acid ester solvent.

Still another aspect of the present invention is
 5 directed to an alternative, non-epichlorohydrin process for manufacturing an epoxy resin of at least one or more phenols utilizing, as an intermediate product, the α -halohydrin intermediate described above.

Detailed Description of the Preferred Embodiments

10 The present invention is directed to a new process for preparing a glycidyl ether of a phenol or a mixture of phenols from a corresponding allyl ether of a phenol or mixture of phenols. In particular, the present invention is directed to a new process for preparing
 15 bisphenol A diglycidyl ether, a common epoxy resin, without the use of epichlorohydrin. This process is outlined generally in the following reaction sequence, Reaction Sequence (III). More specifically, Reaction Sequence (III) shows a process chemistry scheme for
 20 conversion of diallyl ether of bisphenol A to bisphenol A epoxy resin via an α -dihydroxy derivative of bisphenol A.

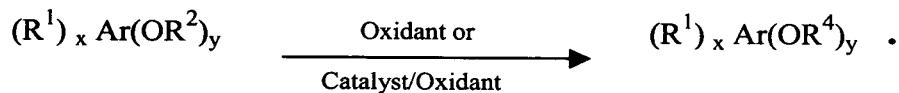
Reaction Sequence (III)



Generally, the present invention includes a process for converting an aryl allyl ether or a mixture of aryl allyl ethers into an α -dihydroxy derivative via a dihydroxylation process by contacting the aryl allyl ether 5 or a mixture of aryl allyl ethers with an oxidant or with an oxidant in combination with a catalyst in an effective amount to form an α -dihydroxy derivative from the aryl allyl ether or mixture of aryl allyl ethers.

The dihydroxylation process of the present 10 invention can be generally described according to the following Scheme I:

Scheme I



The various elements of the above 15 dihydroxylation process equation of Scheme I are disclosed hereinafter in detail in the subheadings which follow herein.

Aryl Allyl Ethers

The starting material in the dihydroxylation 20 process is an aryl allyl ether or mixture of aryl allyl ethers. "Aryl allyl ether compounds" or "aryl allyl ethers" as used herein means (i) allyl ethers that contain an allyl ether moiety connected directly to an aromatic ring; or (ii) allyl ethers that contain an allyl ether 25 moiety and an aromatic ring, but the allyl ether moiety is not connected directly to the aromatic ring, but instead

the allyl ether moiety is linked to the aromatic ring via a linking group such as a polyalkylene oxide group.

In one embodiment of the present invention, the aryl allyl ether or mixture of aryl allyl ethers used in 5 the present invention are those described in U.S. Patent No. 6,087,513, incorporated herein by reference.

In another embodiment of the present invention, the aryl allyl ether or mixture of aryl allyl ethers useful in the present invention are represented by, but 10 not limited to, the structures of the following Formulas I-V. The following Formula I generically represents a preferred class of aryl allyl ethers used in the present invention:

Formula I



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In Formula I, x is from 0 to 750, and y is from 1 to 150. When y is equal to or greater than two, then the aryl allyl ether is a multifunctional allyl ether.

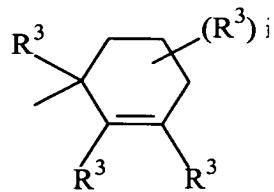
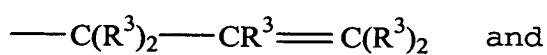
In Formula I, Ar is a moiety containing a 20 mononuclear aromatic ring such as phenyl. Ar may also be a moiety containing multinuclear aromatic rings, such as for example biphenyl, 2,2-diphenyl propane, bisphenylene oxide, tetrakis(1,1,2,2-phenyl)ethane, stilbene, phenol-formaldehyde novolac, cresol-formaldehyde novolac, phenol-25 dicyclopentadiene novolac and hyper-branched aromatic phenol dendrimers. Ar may also be a moiety containing multinuclear fused aromatic rings such as for example

naphthalene, anthracene and naphthalene-formaldehyde novolac. Ar may also be a moiety containing multinuclear fused aromatic rings with one or more heteroatoms such as for example O, N, S, Si, B or P; or any combination of 5 these heteroatoms, such as for example, quinoxaline, thiophene and quinoline. Ar may also be a moiety containing mononuclear or multinuclear aromatic ring(s) fused with a cycloaliphatic ring(s) such as for example indane, 1,2,3,4-tetrahydronaphthalene and fluorene. Ar 10 may also be a moiety containing mononuclear or multinuclear aromatic ring(s) fused with a cycloaliphatic ring(s) containing one or more heteroatoms such as for example O, N, S, Si, B or P; or any combination of these heteroatoms, such as for example, chroman, indoline and 15 thioindane. Ar as described above in Formula I can also be partially or fully fluorinated.

In Formula I, Ar can also be a moiety containing aryl groups in which each aryl group is connected to oligomeric (for example, polymers with less than about 20 5000 molecular weight average) or high molecular weight (for example, greater than about 5000 molecular weight average) organosiloxane units. The aryl groups are attached directly to the Si atoms of the organosiloxane units, or the aryl groups are indirectly attached to the 25 Si atoms of the organosiloxane units via an organic aliphatic moiety, organic cycloaliphatic moiety, organic aromatic moiety, or any combination thereof. The organic aliphatic, cycloaliphatic, or aromatic moiety should contain no more than 20 carbon atoms. When the Ar moiety 30 contains such oligomeric or high molecular weight organosiloxane units, then y is preferably from 2 to 150.

In Formula I, R¹ is a group substituted for a hydrogen atom on the aromatic ring(s) of the Ar moiety. R¹ is a halogen atom such as, for example, bromine or chlorine; or a hydrocarbon radical such as an alkyl group, 5 a cycloaliphatic group or aromatic group. R¹ is preferably an alkyl group having from 1 to 20 carbon atoms such as, for example methyl, ethyl or propyl; a cycloaliphatic group having from 3 to 20 carbon atoms such as, for example, cyclopentyl or cyclohexyl; an aromatic group 10 having from 6 to 20 carbon atoms such as, for example, phenyl or naphthyl; or any combination thereof. The hydrocarbon radicals above may also contain one or more heteroatoms such as, for example, O, N, S, Si, B, P or any combination of these heteroatoms. An example of a 15 hydrocarbon radical containing an O heteroatom is a methoxy group, an ethoxy group or a polyalkylene oxide group derived from ethylene oxide, propylene oxide, butylene oxide or cyclohexene oxide. R¹ as described above in Formula I can be partially or fully fluorinated.

20 In Formula I, O is an oxygen atom substituted for a hydrogen atom on the aromatic ring(s) of the Ar moiety, and R² is, for example, a propenyl-containing moiety preferably selected from:

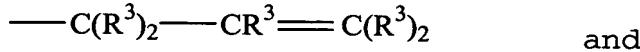


25 where R³ is hydrogen; or an alkyl group, a cycloaliphatic group or aromatic group; and i is from 0 to 6. R³ is

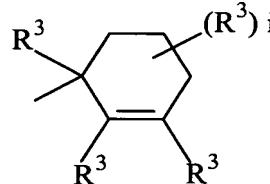
preferably an alkyl group having from 1 to 20 carbon atoms such as, for example, methyl, ethyl or propyl; a cycloaliphatic group having from 3 to 20 carbon atoms such as, for example, cyclopentyl or cyclohexyl; an aromatic group having from 6 to 20 carbon atoms such as, for example, phenyl or naphthyl; or any combination thereof.

5 Each individual R³ may be the same group or may be a different group from each other.

In Formula I, R² may also be a monoalkylene oxide group or a polyalkylene oxide group derived from, for example, ethylene oxide, propylene oxide, butylene oxide or cyclohexene oxide; wherein each monoalkylene oxide group or each polyalkylene oxide group is terminated with, for example, a propenyl-containing moiety selected from:



and



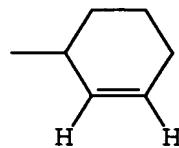
15

where R³ is as described above.

In one embodiment, when R² in Formula I above is —CH₂CH=CH₂, the ether is an "allyl ether."

In another embodiment, when R² is —CH₂C(CH₃)=CH₂ 20 in Formula I above, the aryl ether is a "methallyl ether."

In yet another embodiment, when R² in Formula I above is

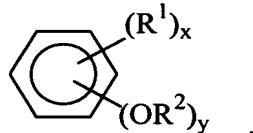


the aryl ether is a "cyclohexen-3-yl ether."

More specific and preferred examples of aryl allyl ethers useful in the present invention are
 5 represented by Formulas II-V which follow.

Examples of mononuclear aryl allyl ethers useful in the present invention are represented by the following Formula II:

Formula II

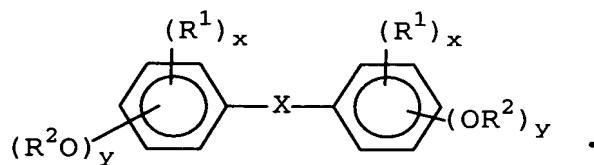


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In Formula II, R¹, O and R² have the same meaning as described above with reference to Formula I. In Formula II, x is from 0 to 5 and y is from 1 to 4. Aryl allyl ethers of Formula II, can be, represented by, for
 15 example, 2-methyl phenyl allyl ether; 4-methyl phenyl allyl ether; 4-methoxyphenyl allyl ether; 2,6-dimethylphenyl allyl ether; 2,6-diisopropylphenyl allyl ether; 2,6-dibromophenyl allyl ether; 1,2-, 1,3- and 1,4-benzene diallyl ethers; 1,4-, 1,5- and 2,6-naphthalene
 20 diallyl ethers; and mixtures thereof.

Other examples of aryl allyl ethers useful in the present invention are binuclear aryl allyl ethers which are represented by the following Formula III:

Formula III



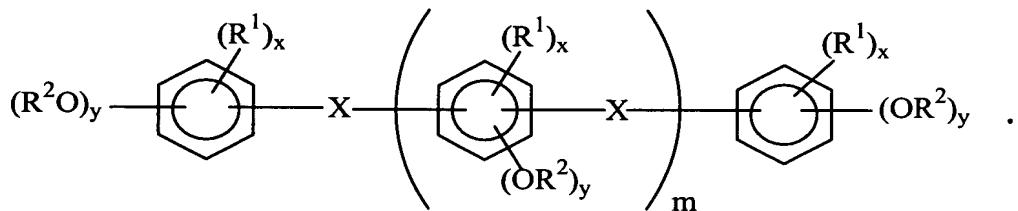
In Formula III, R^1 , O and R^2 have the same
5 meaning as described above with reference to Formula I.
In Formula III, each x is from 0 to 4, and each x can be
the same or different, and each y is from 1 to 4, and each
y can be the same or different.

In Formula III, X may be nil; or X can be a
10 heteroatom with or without substituents thereon to
complete its necessary bonding valence; the heteroatom is
preferably selected from O, N, S, Si, B or P, or any
combination of two or more of the above heteroatoms. X can
also be, for example, $-C(O)-$, $-S(O_2)-$, $-C(O)NH-$, or
15 $-P(O)Ar-$. X can also be, for example an organic aliphatic
moiety, with or without heteroatoms, such as, for example,
oxydimethylene, methylene, 2,2-isopropylidene,
isobutylene, or $-CR^3=CH-$, where R^3 is as defined with
reference to Formula I above. X can also be, for example,
20 a cycloaliphatic group, with or without heteroatoms, such
as, for example, a cycloaliphatic ring with greater than 3
carbon atoms; or an aromatic group, with or without
heteroatoms; or any combination thereof, preferably with
no more than 60 carbon atoms. X as described above in
25 Formula III can be partially or fully fluorinated, such
as, for example, 2,2-perfluoroisopropylidene.

Precursors useful for making the aryl allyl ethers of Formula III include, for example, 4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo-4,4'-dihydroxybiphenyl; bis(4-hydroxyphenyl)methane; bis(4-hydroxyphenyl)sulfone; 2,2-bis(3,5-dibromo-4-hydroxyphenyl)isopropylidene; 2,2-bis(4-hydroxyphenyl)isopropylidene; bisphenol K; 9,9-bis(4-hydroxyphenyl)fluorene; 4,4'-dihydroxy- α -methylstilbene; and 1,3-bis(4-hydroxylphenyl)adamantane.

Other examples of aryl allyl ethers useful in the present invention are multinuclear aryl allyl ethers which are represented by the following Formula IV:

Formula IV



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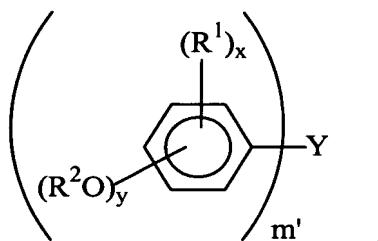
In Formula IV, R¹, O, R² and X have the same meaning as described above with reference to Formula III. In Formula IV, each x is from 0 to 4, and each x can be the same or different, and each y is from 1 to 4, and each y can be the same or different. In Formula IV, m is from 0.001 to 10.

Precursors useful for making the aryl allyl ethers of Formula IV include, for example, phenol-formaldehyde novolac (functionality greater than 2); o-cresol-formaldehyde novolac (functionality greater than

2); phenol-dicyclopentadienyl novolac (functionality greater than 2); and naphthol-formaldehyde novolac (functionality greater than 2).

Other examples of aryl allyl ethers useful in
 5 the present invention are multi-nuclear aryl allyl ethers which are represented by the following Formula V:

Formula V



In Formula V, R¹, O and R² have the same meaning
 10 as described previously with reference to Formula I. In Formula V, each x is from 0 to 4, and each x can be the same or different, and each y is from 1 to 4, and each y can be the same or different.

In Formula V, Y is an organic aliphatic moiety,
 15 with or without heteroatoms such as, for example, O, N, S, Si, B or P, or any combination of two or more of the above heteroatoms, wherein the aliphatic moiety has from 1 to 20 carbon atoms, such as, for example, methine; a cycloaliphatic moiety, with or without heteroatoms, having from 3 to 20 carbon atoms, such as, for example, cyclohexane tri-yl; an aromatic moiety, with or without heteroatoms, such as, for example, benzenetriyl, naphthylenetriyl, fluorenetriyl; or any combination thereof, with no more than about 20 carbon atoms. Y as

described above in Formula V can be partially or fully fluorinated, such as, for example fluoromethine.

In Formula V, m' is generally 3 or 4. However, Y may also be an oligomeric (for example, less than about 5 5000 molecular weight average) organosiloxane unit or high molecular weight (for example, greater than about 5000 molecular weight average) organosiloxane unit. In which case, the aryl groups are attached to the Si atoms of the organosiloxane unit directly or through an organic 10 aliphatic, cycloaliphatic, aromatic group, or any combination thereof, with no more than about 20 carbon atoms. When Y is an oligomeric or high molecular weight organosiloxane unit, m' in Formula V is preferably from 1 to 150.

15 Precursors useful for making the aryl allyl ethers of Formula V include, for example, tris(4-hydroxyphenyl)methane; tris(3,5-dimethyl-4-hydroxyphenyl)methane; and 1,1,2,2'-tetrakis(4-hydroxyphenyl)ethane.

20 Even more particularly, the process of the present invention utilizes aryl diallyl ethers or aryl multifunctional allyl ethers. An example of an aryl diallyl ether useful in the present invention includes the diallyl ether of bisphenol A.

25 Typically, the aryl allyl ethers used in the present invention are made from phenolic compounds or hydroxy-containing aromatic compounds.

Phenolic Compounds

The hydroxy moiety of the hydroxy-containing aromatic compound can be directly attached to the aromatic ring of the hydroxy-containing aromatic compound, in which
5 case it is a phenolic compound; or the hydroxy moiety may not be connected directly to the aromatic ring, but instead the hydroxy moiety may be linked to the aromatic ring via a linking group such as a polyalkylene oxide group.

10 The phenolic compound useful in the above process for synthesizing the aryl allyl ether, is represented by, but not limited to, any one of the structures of the following Formulas VI-X. A preferred class of phenolic compounds useful in the present
15 invention for reacting with an allylating agent to make an α -dihydroxy derivative is generically represented by the following Formula VI:

Formula VI

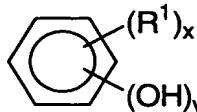


20 In Formula VI, x, y, Ar and R¹, are as defined previously for Formula I, and OH is a hydroxyl group substituted for a hydrogen atom on the aromatic ring(s) of the Ar moiety.

25 More specific and preferred examples of phenolic compounds useful in the present invention are represented by Formulas VII-X, separately or as mixtures of two or more phenolic compounds of Formulas VII-X which follow.

Examples of mononuclear phenolic compounds useful in the present invention are represented by the following Formula VII:

Formula VII



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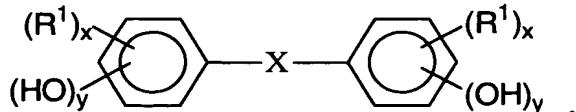
In Formula VII, x , y and R^1 have the same meaning as described above with reference to Formula II, and OH has the same meaning as described above with reference to Formula VI.

10 Included among the compounds represented by Formula VII are, for example, 2-methylphenol; 4-methylphenol; 4-methoxyphenol; 2,6-dimethylphenol; 2,6-diisopropylphenol; 2,6-dibromophenol; 1,2-, 1,3- and 1,4-dihydroxybenzene; 1,4-, 1,5- and 2,6-dihydroxy
15 naphthalene; and mixtures thereof.

Other examples of phenolic compounds useful in the present invention are binuclear phenolic compounds which are represented by the following Formula VIII:

20

Formula VIII



In Formula VIII, x , y , R^1 and X have the same meaning as described above with reference to Formula III,

and OH has the same meaning as described above with reference to Formula VI.

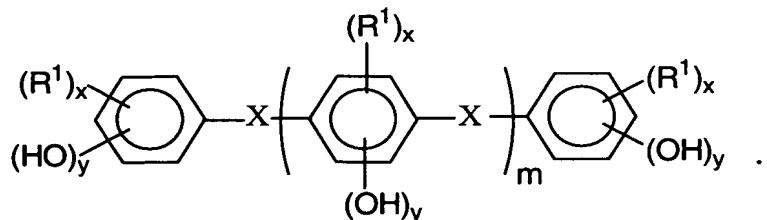
Included among the phenolic compounds represented by Formula VIII are, for example,

- 5 4,4'-(3,3'5,5'-tetramethyl)bisphenol A; 4,4'-(3,3'5,5'-tetramethyl-2,2',6,6'-tetrabromo)bisphenol A;
- 10 4,4'-(3,3'5,5'-tetramethyl)bisphenol F; 4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo-4,4'-dihydroxybiphenyl; bis(4-
- 15 hydroxyphenyl)methane; bis(4-hydroxyphenyl)sulfone; 2,2-bis(3,5-dibromo-4-hydroxyphenyl)isopropylidene; 2,2-bis(4-hydroxyphenyl)isopropylidene; 4,4'-bisphenol K; 9,9-bis(4-hydroxyphenyl)fluorene; 4,4'-dihydroxy- α -methylstilbene;
- 20 1,3-bis(4-hydroxylphenyl)adamantane; and mixtures thereof.

Other examples of phenolic compounds useful in the present invention are multinuclear phenolic compounds which are represented by the following Formula IX:

20

Formula IX

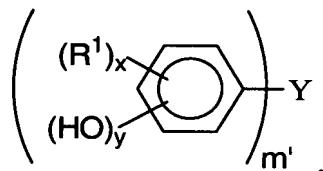


In Formula IX, x, y, R¹, X and m have the same meaning as described above with reference to Formula IV, and OH has the same meaning as described above with reference to Formula VI.

Included among the phenolic compounds represented by Formula IX are, for example, phenol-formaldehyde novolac (functionality greater than 2); o-cresol-formaldehyde novolac (functionality greater than 2); phenol-dicyclopentadienyl novolac (functionality greater than 2); naphthol-formaldehyde novolac (functionality greater than 2); and mixtures thereof.

Other examples of phenolic compounds useful in the present invention are multi-nuclear phenolic compounds which are represented by the following Formula X:

Formula X



In Formula X, x, y, R¹, Y and m' have the same meaning as described above with reference to Formula V, and OH has the same meaning as described above with reference to Formula VI.

Included among the phenolic compounds represented by Formula X are, for example, tris(4-hydroxyphenyl)methane; tris(3,5-dimethyl-4-hydroxyphenyl)methane; 1,1,2,2-tetrakis(4-hydroxyphenyl)ethane; and mixtures thereof.

Preferred phenolic compounds of the present invention include more specifically, the phenols, such as for example, 1,3-dihydroxybenzene; 1,4-dihydroxybenzene; 1,5-dihydroxynaphthalene; 2,6-dihydroxynaphthalene; 4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-4,4'-

dihydroxybiphenyl; 3,3',5,5'-tetramethyl-2,2',6,6'-
tetrabromo-4,4'-dihydroxybiphenyl; bis(4-
hydroxyphenyl)methane; 4,4'-bis(2,6-
dibromophenol)isopropylidene; 2,2-bis(4-
5 hydroxyphenyl)isopropylidene; phenol-formaldehyde novolac
(functionality >2); o-cresol-formaldehyde novolac
(functionality >2); phenol-dicyclopentadienyl novolac
(functionality >2); naphthol-formaldehyde novolac
(functionality >2); tris(4-hydroxyphenyl) methane;
10 1,1,2,2-tetrakis(4-hydroxyphenyl)ethane; and mixtures
thereof.

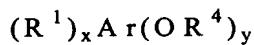
The phenols or mixtures of phenols described above are used to make the aryl allyl ethers useful in the present invention. The aryl allyl ethers useful in the 15 present invention may be synthesized by reacting, for example, an allylating agent such as for example, allyl chloride, allyl bromide, methallyl chloride, allyl acetate, allyl alcohol or allyl carbonate with a phenol, a mixture of phenols, or a hydroxy-containing aromatic 20 compound. The reaction between the phenol, mixture of phenols or hydroxy-containing aromatic compound, and the allylating agent may be done with or without catalysts or with or without bases, for example, as disclosed in U.S. Patent Nos. 5,578,740; 4,740,330 and 4,507,492; 25 incorporated herein by reference.

Typically, the α -dihydroxy derivatives used in the present invention are made from the aryl allyl ethers prepared above. The α -dihydroxy derivatives, in turn, are useful in manufacturing epoxy resins of the present 30 invention.

α -Dihydroxy Derivatives

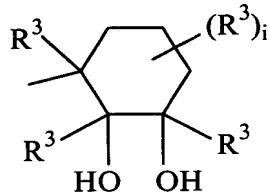
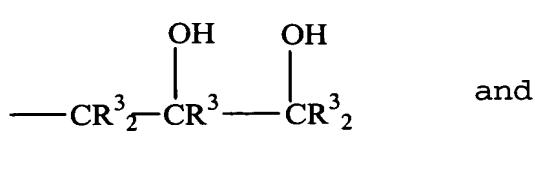
The preferred α -dihydroxy derivatives useful in the present invention are represented for example by, but not limited to, the structures of the following Formulas 5 XI-XV. A preferred class of α -dihydroxy derivatives used in the present invention is generically represented for example by the following Formula XI:

Formula XI



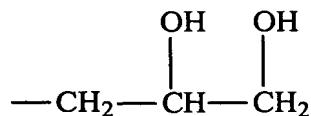
10 In Formula XI, x, y, Ar, O and R^1 are as defined in Formula I.

In Formula XI, R^4 is an α -dihydroxy propyl-containing moiety preferably selected from:



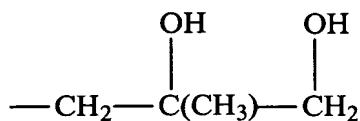
15 wherein R^3 and i are defined previously for Formula I and OH is a hydroxyl group.

In one embodiment, when R^4 in Formula XI above is the following structure:



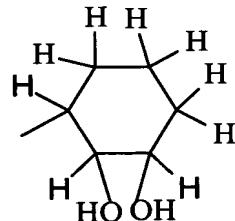
the α -dihydroxy derivative is an α -dihydroxy derivative of an aryl "allyl ether."

In another embodiment, when R⁴ in Formula XI
5 above is the following structure:



the α -dihydroxy derivative is an α -dihydroxy derivative of an aryl "methallyl ether."

In yet another embodiment, when R⁴ in Formula XI
10 above is the following structure:

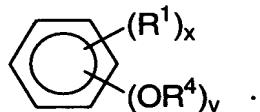


the α -dihydroxy derivative is an α -dihydroxy derivative of an aryl "cyclohexene-3-yl ether."

More specific and preferred examples of α -
15 dihydroxy derivatives useful in the present invention are represented by Formulas XII-XV separately or as mixtures of two or more α -dihydroxy derivatives of Formulas XII-XV which follow.

Examples of mononuclear aromatic α -dihydroxy derivatives useful in the present invention are represented by the following Formula XII:

Formula XII



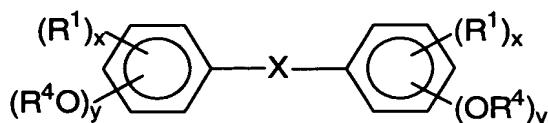
5

In Formula XII, x , y , O and R^1 have the same meaning as described above with reference to Formula II. In Formula XII, R^4 has the same meaning as described above with reference to Formula XI. α -Dihydroxy derivatives of Formula XII can be prepared from aromatic hydroxyl group-containing precursors, such as, for example, 2-methylphenol; 4-methylphenol; 4-methoxyphenol; 2,6-dimethylphenol; 2,6-diisopropylphenol; 2,6-dibromophenol; 1,2-, 1,3- and 1,4-dihydroxybenzene; 1,4-, 1,5- and 2,6-dihydroxynaphthalene; or mixtures thereof.

Other examples of α -dihydroxy derivatives useful in the present invention are binuclear aromatic α -dihydroxy derivatives which are represented by the following Formula XIII:

20

Formula XIII



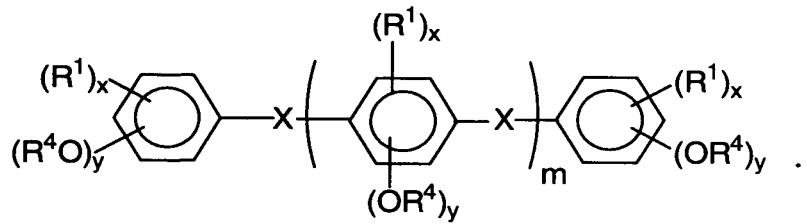
In Formula XIII, x , y , X , O and R^1 have the same meaning as described above with reference to Formula III.

In Formula XIII, R⁴ has the same meaning as described above with reference to Formula XI.

Precursors useful for making the α -dihydroxy derivatives of Formula XIII include, for example, 4,4'-5 dihydroxybiphenyl; 3,3',5,5'-tetramethyl-4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo-4,4'-dihydroxybiphenyl; bis(4-hydroxyphenyl)methane; bis(4-hydroxyphenyl)sulfone; 2,2-bis(3,5-dibromo-4-hydroxyphenyl)isopropylidene; 2,2-bis(4-hydroxyphenyl)isopropylidene; bisphenol K; 9,9-bis(4-hydroxyphenyl)fluorene; 4,4'-dihydroxy- α -methylstilbene; 1,3-bis(4-hydroxylphenyl)adamantane; or mixtures thereof.

Other examples of α -dihydroxy derivatives useful in the present invention are multi-nuclear aromatic α -15 dihydroxy derivatives which are represented by the following Formula XIV:

Formula XIV



In Formula XIV, x, y, X, m, O and R¹ are as described above for Formula IV. In Formula XIV, R⁴ has the same meaning as described above with reference to Formula XI.

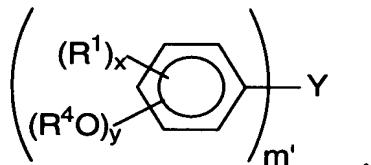
Precursors useful for making the α -hydroxy ester derivatives of Formula XIV include, for example, phenol-

formaldehyde novolac (functionality greater than 2); o-cresol-formaldehyde novolac (functionality greater than 2); phenol-dicyclopentadienyl novolac (functionality greater than 2); naphthol-formaldehyde novolac
5 (functionality greater than 2); or mixtures thereof.

Other examples of α -dihydroxy derivatives useful in the present invention are multi-nuclear aromatic α -dihydroxy derivatives which are represented by the following Formula XV:

10

Formula XV



In Formula XV, x, y, Y, m', O and R¹ are the same as previously described above for Formula V. In Formula XV, R⁴ has the same meaning as described previously with
15 reference to Formula XI.

Precursors useful for making the α -dihydroxy derivatives of Formula XV include, for example, tris(4-hydroxyphenyl)methane; tris(3,5-dimethyl-4-hydroxyphenyl)methane; 1,1,2,2-tetrakis(4-hydroxyphenyl)ethane; or mixtures thereof.
20

Preferred α -dihydroxy derivatives useful in the present invention include, for example, (2,3- α -dihydroxypropyl)ether of 2-methylphenol; (2,3- α -dihydroxypropyl)ether of 4-methylphenol; (2,3- α -dihydroxypropyl)ether of 4-methoxyphenol; (2,3- α -
25

dihydroxypropyl)ether of 2,6-dimethylphenol; (2,3- α -dihydroxypropyl)ether of 2,6-diisopropylphenol; (2,3- α -dihydroxypropyl)ether of 2,6-dibromophenol; bis(2,3- α -dihydroxypropyl)ether of 1,2-, 1,3- and 1,4-
5 dihydroxybenzene; bis(2,3- α -dihydroxypropyl)ether of 1,4-, 1,5- and 2,6-dihydroxynaphthalene; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl)bisphenol A; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo)bisphenol A; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl)biphenol; bis(2,3- α -dihydroxypropyl)ether of 4,4'-biphenol; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo)biphenol;
10 bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl)bisphenol F; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl)biphenol; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo)biphenol;
15 bis(2,3- α -dihydroxypropyl)ether of 4,4'-bisphenol F; bis(2,3- α -dihydroxypropyl)ether of 4,4'-bisphenol sulfone; bis(2,3- α -dihydroxypropyl)ether of 4,4'-(3,3',5,5'-tetramethyl)bisphenol A; bis(2,3- α -dihydroxypropyl)ether of
20 4,4'-bisphenol A; bis(2,3- α -dihydroxypropyl)ether of 4,4'-bisphenol K; bis(2,3- α -dihydroxypropyl)ether of 9,9-bis(4-hydroxyphenyl)fluorene; bis(2,3- α -dihydroxypropyl)ether of 4,4'-dihydroxy- α -methylstilbene; bis(2,3- α -dihydroxypropyl)ether of 1,3-bis(4-
25 hydroxyphenyl)adamantane; (2,3- α -dihydroxypropyl)ether of phenol-formaldehyde novolac (functionality >2); (2,3- α -dihydroxypropyl)ether of o-cresol-formaldehyde novolac (functionality >2); (2,3- α -dihydroxypropyl)ether of phenol-dicyclopentadienyl novolac (functionality >2);

(2,3- α -dihydroxypropyl)ether of naphthol-formaldehyde novolac (functionality >2); tris(2,3- α -dihydroxypropyl)ether of trisphenylol methane; tris(2,3- α -dihydroxypropyl)ether of tris(3,5-dimethyl-4-
5 hydroxyphenyl)methane; tetra(2,3- α -dihydroxypropyl)ether of 1,1,2,2-tetraphenylol ethane; and mixtures thereof.

Generally, the present invention includes a process for converting an aryl allyl ether or mixture of two or more aryl allyl ethers into an α -dihydroxy derivative via a dihydroxylation process by contacting the aryl allyl ether ether or mixture of two or more aryl allyl ethers with an oxidant, or with an oxidant and a catalyst, effective to form an α -dihydroxy derivative from the aryl allyl ether or mixture of two or more aryl allyl ethers.
10
15

Dihydroxylation Processes

α -Dihydroxylation of aryl allyl ethers is carried out using either one of two basic processes: (i) a non-catalytic process in which dihydroxylation of the aryl allyl ether is carried out using only an oxidant; or (ii) a catalytic process in which dihydroxylation of the aryl allyl ether is carried out using an oxidant in the presence of a catalyst.
20
25

In addition, α -dihydroxylation of aryl allyl ethers to form an α -dihydroxy derivative is carried out either in (i) a direct or (ii) an indirect process.

In the direct α -dihydroxylation process, the allyl groups of the aryl allyl ether are oxidized directly to the α -dihydroxy derivative. The direct α -dihydroxylation process is accomplished by any one of a number of α -dihydroxylation reaction processes well-known to those skilled in the art, such as, for example, by reacting the aryl allyl ether with an oxidizing material or by reacting the aryl allyl ether with an oxidizing material in the presence of a catalyst.

In the indirect α -dihydroxylation process, the allyl groups of the aryl allyl ether are oxidized indirectly to the α -dihydroxy derivative. In the indirect α -dihydroxylation process, the allyl groups of the aryl allyl ether are first oxidized to a transient epoxide intermediate, which may or may not be observed. When the transient epoxide intermediate is not observed it is essentially instantaneously converted *in situ* into an α -dihydroxy derivative. The indirect α -dihydroxylation process is accomplished by any one of a number α -dihydroxylation reaction processes well-known to those skilled in the art, such as, for example, by reacting the aryl allyl ether with an oxidizing material or by reacting the aryl allyl ether with an oxidizing material in the presence of a catalyst.

The direct and indirect α -dihydroxylation processes are not always clearly distinguishable one from the other, and, in fact, it is sometimes not possible to identify which of these two processes is occurring during an α -dihydroxylation process. Though in the following

description of the present invention, the direct and indirect α -dihydroxylation processes are differentiated and described separately. These descriptions should not be taken as definitive since as discussed above the
5 distinction of the direct and indirect dihydroxylation processes are not always obvious from the other.

Non-Catalytic Dihydroxylation Processes

In the non-catalytic α -dihydroxylation process, the allyl groups of the aryl allyl ethers of the present
10 invention are dihydroxylated using only an oxidant.

One category of oxidants, useful in the non-catalytic α -dihydroxylation process may be, for example, aromatic and aliphatic organic peracids, organic peroxyimidic acids, selenic peracids, and dioxiranes.

15 In one embodiment of the present invention, non-catalytic α -dihydroxylation processes using peracid may be used to form α -dihydroxylation derivatives of aryl allyl ethers in good to excellent yields. Peracids useful in the present invention may include for example, aromatic
20 peracids, such as, for example, m-chloroperbenzoic acid, peroxybenzoic acid, and monoperoxyphthalic acid; aliphatic peracids, such as, for example, peracetic acid (also known as peroxyacetic acid) as described, for example, by C. Y. Curtin, et al., in J. Amer. Chem. Soc., 78, pp. 1726,
25 (1956) and by L. S. Abott in U.S. Patent No. 2,714,602, both of which are incorporated herein by reference; or peroxyimidic acids, such as the one described by R. Murry

in J. Org. Chem., 63, pp. 1730-1731, (1998), incorporated herein by reference.

In another embodiment of the present invention, peracid oxidants may be generated *in situ* in a non-
5 catalytic dihydroxylation process. For instance, organic nitriles, such as acetonitrile, may be reacted with air, oxygen, hydrogen peroxide, or organic hydroperoxide to form *in situ* peroxyimidic acids; and carboxylic acids or carboxylic acid anhydrides, such as acetic acid or acetic
10 anhydride, may be reacted with air, oxygen, hydrogen peroxide, or organic hydroperoxides to form *in situ* peroxycarboxylic acids. In particular, the peroxycarboxylic acid oxidants can be generated *in situ* by reaction of air, or oxygen, with the corresponding
15 aliphatic aldehyde, as described in U.S. Patent No. 4,721,798, which is incorporated herein by reference.

Also, another example of *in situ* generated peracids are the selenic peracids, such as for example, the selenic peracids generated from diselenides and
20 hydrogen peroxide as described by R. A. Sheldon, *et al.*, in J. Chem. Soc., Perkin Trans. 1, pp. 224-228, (2001), which is incorporated herein by reference.

In yet another embodiment of the present invention, organic dioxiranes may be used in non-catalytic
25 α -dihydroxylation processes to form α -dihydroxy derivatives of aryl allyl ethers. Organic dioxiranes useful for the non-catalytic dihydroxylation process, include, for example, dimethyldioxarane as described, for example, by R. Murry in Chem. Rev., 89, pp. 1187-1201,
30 (1989); perfluorodimethyldioxaranes, which may be made

from a perfluoroketone and hydrogen peroxide, as described, for example, by R. Sheldon in Synlett, (2), pp. 248-250 (2001); and heterogenous or resin-bound *in situ* formed dioxiranes such as described, for example, by T. R. 5 Boehlow, *et al.*, in Tetrahedron Letters, 39, pp. 1839-1842, (1989) and by R. Newmann, *et al.*, in Chemical Communications, (5), pp. 487-488, (2001); all of which are incorporated herein by reference.

A second category of oxidants useful in the non-10 catalytic α -dihydroxylation process, includes oxides of osmium, such as osmium tetroxide (OsO_4). When osmium tetroxide is used as an oxidant in the α -dihydroxylation process, it is used in a stoichiometric amount relative to the number of equivalents of allyl ether groups to be 15 dihydroxylated. Thus, in this type of α -dihydroxylation process, osmium is not used as a catalyst but as a stoichiometric reagent.

Other oxidants which may be used in the α -dihydroxylation process of the present invention include, 20 for example, organic N-oxides; persulfates; and oxidizing metal salts, such as $\text{K}_3\text{Fe}(\text{CN})_6$, or KIO_4 , and the like.

In a preferred embodiment of the present invention, the ratio of the oxidant used for 25 dihydroxylation of the aryl allyl ether in a non-catalytic dihydroxylation process is preferably in the range of from about 0.6 mole to about 20 moles of oxidant to 1 equivalent of aryl allyl ether. More preferably, the ratio of oxidant used for dihydroxylation of the aryl allyl ether is in the range of from about 1 mole to about

5 moles of oxidant to 1 equivalent of aryl allyl ether. The most preferred ratio for oxidant used for non-catalytic dihydroxylation of the aryl allyl ether is from about 1 mole to about 2.5 moles of oxidant to 1 equivalent of aryl allyl ether. One equivalent of oxidant is theoretically required to oxidize one equivalent of a aryl mono-allyl ether substrate, but it may be desirable to employ an excess of oxidant to optimize conversion to the α -dihydroxy derivative.

10 Catalytic Dihydroxylation Processes

In catalytic α -dihydroxylation process, the allyl groups of the aryl allyl ethers of the present invention are dihydroxylated catalytically using preferably a transition metal catalyst from the group comprising Group IVA, Group VA, Group VIA, Group VIIA, and Group VIII transition metals or a Group VIB (old IUPAC group notation) element catalyst and an oxidant.

Among the transition metal- or Group VIB element-containing catalysts more preferably useful in the present invention are the catalysts having transition metals or Group VIB elements selected from the group comprising Os, Mn, Re, Ru, W, Cr, Mo, V, Ti, Se, Te or mixtures thereof.

The catalysts useful for dihydroxylation of allyl ether groups of aryl allyl ether compounds are classified as either (i) direct α -dihydroxylation catalysts or (ii) indirect α -dihydroxylation catalysts. The dihydroxylation catalyst is classified as a direct α -dihydroxylation catalyst or as an indirect α -

dihydroxylation catalyst dependent on the chemical mechanism through which the dihydroxylation catalyst converts the aryl allyl ether to the α -dihydroxy derivative as discussed previously above.

5 Catalytic, direct α -dihydroxylation of allyl ether groups of aryl allyl ether compounds is done by oxidizing the allyl ether groups directly to yield the α -dihydroxy derivative. In one embodiment of the present invention, the most preferred transition metal complexes
10 or compounds useful as direct α -dihydroxylation catalysts may be selected from the group of transition metals comprising, Os, Mn, Re, Ru or mixtures thereof.

In another embodiment of the present invention, the most preferred transition metal catalysts useful as α -dihydroxylation catalysts are compounds or complexes of osmium. The general use of osmium-based dihydroxylation catalysts is well-known to those skilled in the art and is reviewed comprehensively by K. B. Sharpless, *et al.*, in "Catalytic Asymmetric Synthesis", pp. 357-398, Second
20 Edition, Edited by Iwao Ojima, Wiley-VCH, 2000; and by I. E. Marko, *et al.*, "Dihydroxylation of Carbon-Carbon Double Bonds", pp. 713-787 in Compr. Asymmetric Catal. I-III, 2, Edited by E. N. Jacobsen, *et al.*, Springer-Verlag, Berlin, Germany (1999), both of which are incorporated herein by
25 reference.

The use of homogeneous osmium-based dihydroxylation catalysts containing asymmetric ligands is well-known to those skilled in the art and is described in U.S. Patent Nos. 4,496,779; 4,871,855; 4,965,364;

5,126,494; 5,227,543; 5,260,461; and 5,516,929; and WO Patent No. 92/20677; all of which are incorporated herein by reference.

It is also known in the art to use homogeneous,
5 recyclable osmium-based dihydroxylation catalysts which are bound to basic ligands, such as alkaloids. Such homogeneous, recyclable osmium-based dihydroxylation catalysts are homogeneous during the α -dihydroxylation process but are precipitated from the reaction mixture at
10 the end of the reaction, as described by K. D. Janda, et al., in J. Am. Chem. Soc., 118(32), pp. 7632-7633 (1996); in PCT Int. Appl.; and in WO 9835927 A1; all of which are incorporated herein by reference.

The use of recyclable, heterogeneous osmium-based dihydroxylation catalysts is well-known to those skilled in the art and is comprehensively reviewed by D. Pini, et al., in Chim. Ind. (Milan), 81(2), pp. 189-199, (1999). In addition, the use of heterogeneous, alkaloid supported polymeric osmium-based dihydroxylation catalysts
20 is described by C. Bolm, et al., in Synlett, No.1, pp. 93-95, (2001); and by P. Salvadori, et al., in Synlett, No.8, pp. 1181-1190, (1999). It is also known to use heterogeneous, polymer-supported or immobilized osmium salts for catalytic dihydroxylations as described by P. A.
25 Jacobs, et al., in Angew. Chem. Int. Ed., 40, No. 3, pp. 586-589 (2001); and by S. Kobayashi, et al., in J. Am. Chem. Soc., 121(48), pp. 11229-11230, (1999). All of the above-mentioned references are incorporated herein by reference.

In another embodiment of the present invention, the transition metal catalysts useful as α -dihydroxylation catalysts are compounds or complexes of manganese. The use of homogeneous manganese-based dihydroxylation catalysts is well-known to those skilled in the art and is described, for instance, by D. E. J. E. De Vos, et al., in European Patent EP 98-202315 and in Chem. Commun., pp. 917-918, (1996); by J. H. Kek, et al., Inorganica Chimica Acta, 295, pp. 189-199, (1999); by A. J. Fatiadi in Synthesis, 85 (1987); and by P. Pietikainen, J. Mol. Catal. A: Chem., 165, (1-2), pp. 73-79, (2001); all of which are incorporated herein by reference.

The use of recyclable, supported, heterogeneous manganese-based dihydroxylation catalysts is well-known to those skilled in the art and is described, for instance, by P. A. Jacobs, et al., in European Patent EP 970951; in Angew. Chem. Int. Ed., 38, No. 7, pp. 980-983, (1999); and in J. Molecular Catalysis A: Chemical, 117, pp. 57-70, (1997); and by D. Brunel, et al., Chem. Commun., pp. 2485 -2486, (1996); all of which are incorporated herein by reference.

In yet another embodiment of the present invention, the transition metal catalysts useful as α -dihydroxylation catalysts are compounds or complexes of rhenium. The use of rhenium-based dihydroxylation catalysts is well-known to those skilled in the art and is comprehensively reviewed, for instance, by W. A. Hermann, et al., in Chemical Reviews, 97, (8), pp. 3197-3246, (1997) and in Accounts of Chemical Research, 30, (4), pp. 169-180, (1997); and by M. M. Abu-Omaret, et al., in

Catalysis Today, 55, pp. 317-363, (2000); and is described, for instance, by W. A. Hermann, et al., Angew. Chem., Int. Ed. Engl., 30, (12), pp. 1638-1643, (1991); by A. K. Rappe, et al., Organometallics, (17), pp. 2716-2719, (1998); by W. Adams, in Angew. Chem., Int. Ed. Engl., 35, (5), pp. 533-535, (1996); and by J. Espenson, et al., in J. Org. Chem., 61, pp. 3969-3976, (1996) and in Inorg. Chem., Vol. 37, pp. 467-472, (1998); all of which are incorporated herein by reference.

10 In still another embodiment of the present invention, the transition metal compounds or complexes useful as α -dihydroxylation catalysts are compounds or complexes of ruthenium. The use of ruthenium-based dihydroxylation catalysts is well-known to those skilled 15 in the art and is described, for instance, by T.K.M. Shing, et al., in Angew. Chemie., 106, pp. 2408, (1994); in Angew. Chemie Int. Ed. Eng., 33, pp. 2312, (1994); in Chem.-Eur. J., 2, pp. 50, (1996); and in Tetrahedron Lett., 40, pp. 2179, (1999); all of which are incorporated 20 herein by reference.

In an alternative, indirect dihydroxylation process, catalytic α -dihydroxylation of allyl ether groups of aryl allyl ether compounds, is done by oxidizing the allyl ether groups indirectly to the α -dihydroxy derivative. In the indirect dihydroxylation process, a transient epoxide group intermediate is formed first. The transient epoxide group intermediate may or may not be observed, and the transient epoxide groups of an aryl allyl ether compound are subsequently converted *in situ* in 25 the presence of the dihydroxylation catalyst and oxidant 30

material into the α -dihydroxy derivative. In the indirect α -dihydroxylation process, the reaction product is an α -dihydroxy derivative which may include small amounts of epoxide intermediate which were not transformed into the
5 α -dihydroxy derivative. In the indirect α -dihydroxylation process, the conversion of the transient epoxy intermediate is caused by the acidic properties of the transition metal dihydroxylation catalyst.

In one embodiment of the present invention, the
10 catalyst in an indirect α -dihydroxylation process may be a compound or complex of a transition metal or a Group VIA element selected from the group comprising, for example, W, Cr, Mo, Re, V, Ti, Se or mixtures thereof.

In yet another embodiment of the present
15 invention, the transition metal compounds or complexes useful as indirect α -dihydroxylation catalysts are compounds or complexes of titanium. The use of titanium silicate molecular sieves as dihydroxylation catalysts under triphase reaction conditions is described by A.
20 Bhaumik, et al., in J. Catal., 176, (2), pp. 305-309, (1998); and by G. Thiele, et al., in U.S. Patent No. 6,100,412; both of which are incorporated herein by reference.

The transition metal and Group VIB element
25 complexes or compounds useful as α -dihydroxylation catalysts may be soluble and act as homogeneous catalysts or alternatively they may be covalently or ionically bound to a solid support and act as a heterogenous catalyst.

The transition metal and Group VIB element complexes or compounds useful as α -dihydroxylation catalysts may be racemic catalysts or they may be asymmetric catalysts, as taught in the known art.

5 The concentration of α -dihydroxylation catalyst useful in the present invention is preferably from about 1×10^{-6} to about 1 mole of transition metal or Group VIB element catalyst per 1 mole of aryl allyl ether present in the reaction mixture.

10 When the dihydroxylation catalysts are heterogenous catalysts, the heterogeneous dihydroxylation catalysts are formulated so the total weight of the transition metal or Group VIB element relative to the weight of the solid support material is in the range of 15 from about 1×10^{-6} parts to about 1 part of transition metal or Group VIB element per 1 part of solid support. The amount of heterogeneous α -dihydroxylation catalyst useful in the present invention is preferably in the range of from about 10^{-3} parts to about 100 parts of heterogeneous 20 catalyst to 1 part of aryl allyl ether in the dihydroxylation reaction mixture.

The transition metal and Group VIB element complexes or compounds useful as α -dihydroxylation catalysts may be used in the presence of certain 25 additives, co-catalysts, and co-oxidants.

Additives, Co-Catalysts, and Co-oxidants for the Catalytic Dihydroxylation Process

In one embodiment of the present invention, catalytic dihydroxylation of allyl ether groups of aryl allyl ether compounds is carried out by oxidizing the allyl ether groups in the presence of additives, co-catalysts, or co-oxidants.

The additives used in catalytic dihydroxylation of allyl ether groups of aryl allyl ether compounds include, for example, such compounds as tertiary amine compounds and compounds used to control dihydroxylation reaction pH between about 7.5 to about 13. Such compounds used to control reaction pH are described, for example, by M. Beller, et al., in PCT WO 2000064848 A1 and in Tetrahedron Lett., 41, (42), pp. 8083-8087, (2000); both of which are incorporated herein by reference.

The co-catalysts used in catalytic dihydroxylation of allyl ether groups of aryl allyl ether compounds may include compounds which are hydrolysis aids such as, for example, salts of alkyl sulfonamides or alkyl carboxylates or methanesulfonamide which are described by K. Sharpless, et al., in J. Org. Chem., 57, (10), pp. 2768-71, (1992), which is incorporated herein by reference.

The co-oxidants used in catalytic dihydroxylation of allyl ether groups of aryl allyl ether compounds include salts such as, for example, copper I and copper II salts, which are beneficial in reducing the energy requirement to re-oxidize the reduced form of the

oxidant. Such co-oxidants are known to those skilled in the art. The co-oxidants are described for instance by J-E. Baeckvall, et al., in J. Am. Chem. Soc., 121, (44), pp. 10424-10425, (1999); by K. Bergstad, et al., in J. Am. Chem. Soc., 121, (44), pp. 10424-10425, (1999); A. Ell, et al. Tetrahedron Letters, 42, 2569-2571, (2001); and by M. Mrksich, et al., Langmuir, 15, (15), pp. 4957-4959, (1999); all of which are incorporated herein by reference. Co-oxidants include, for example, naturally occurring 10 flavones and their synthetic analogs, as well as several metal salts and complexes, such as for example, metal salts and complexes of V, Zr, Hf, Ti, Nb, Ta, W, Mo, Mn or mixtures thereof.

In one embodiment of the present invention, the 15 amount of additive, co-catalyst, or co-oxidant used should not be detrimental to the α -dihydroxylation process. It is preferred to use an amount of additive, co-catalyst, or co-oxidant which is less than about 1×10^{-3} mole to about 0.20 mole of the additive, co-catalyst, or co-oxidant per 20 equivalent of aryl allyl ether moieties which are being reacted in the dihydroxylation process. More preferably the amount of additive, co-catalyst, or co-oxidant used is less than about 1×10^{-3} mole to about 0.10 mole of the additive, co-catalyst, or co-oxidant per equivalent of 25 aryl allyl ether moieties which are being reacted in the dihydroxylation process. Most preferably, the amount of additive, co-catalyst, or co-oxidant used may be less than about 1×10^{-3} mole to about 0.05 mole of the additive, co-catalyst, or co-oxidant per equivalent of aryl allyl ether 30 moieties which are being reacted in the dihydroxylation process.

Oxidants for the Catalytic Dihydroxylation Process

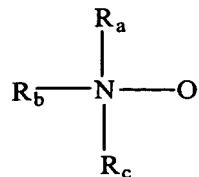
α-Dihydroxy derivatives, in general, and α-dihydroxy derivatives of aryl allyl ether, in particular, can be prepared by oxidizing the corresponding allyl ether 5 by catalytic oxidation using, for example, air, oxygen, an oxygen-gas(es) mixture, hydrogen peroxide, tertiary organic amine N-oxides, organic hydroperoxides, periodate salts, hypochlorite salts, persulfate salts, or iron III salts as oxidants.

In one embodiment of the present invention, air or oxygen is preferably used as the oxidant for the dihydroxylation of aryl allyl ethers of the present invention. The use of air or oxygen as an oxidant for dihydroxylation is comprehensively reviewed by T. Wirth, 10 Angew. Chem., Int. Ed., 39, (2), pp. 334-335, (2000) and by R. G. Austin, et al., in Catalysis of Organic Reactions, R. L. Augustine, Editor, pp. 269 (1985); and described by R. C. Michaelson, et al., in U.S. Patent Nos. 15 4,413,151 and 4,314,088; and in European Patent 0,077,201 A2; 19830628; by R.G. Austin, et al, in Catalysis of Organic Reactions, R.L. Augustine, Ed. pp. 269, (1985); by R. S. Meyers, et al., in U.S. Patent No. 4,496,779; by R. C. Michaelson, et al., EP 0077201 A2 830420; by T. Wirth in Angew. Chemie Int. Ed. Eng., 2, pp. 334, (2000); by C. Dobler, et al., in Angew. Chemie Int. Ed. Eng., 38, pp. 20 3026, (1999); and by M. Beller, et al., in WO Patent Application 2000064844 A1 and in J. Am. Chem. Soc., 122, (42), pp. 10289-10297, (2000); all of which are incorporated herein by reference.

When oxygen is used as oxidant in the catalytic dihydroxylation process, oxygen may be present as pure oxygen, or the oxygen may be present as a mixture of gases. It is preferred to use nitrogen in mixtures of 5 gases containing oxygen. When oxygen is used as a mixture of gases, the oxygen is preferably present from about 1% to about 100% on a volume basis.

In another embodiment of the present invention, an oxidant useful in the dihydroxylation process for 10 reacting aryl allyl ethers of the present invention is hydrogen peroxide as described by K. Bergstad, et al., J. Am. Chem. Soc., 121, (44), pp. 10424-10425, (1999); and by A. Ell, et al. Tetrahedron Letters, 42, 2569-2571, (2001); both of which are incorporated herein by reference. 15 Generally, the hydrogen peroxide used is an aqueous hydrogen peroxide containing from about 3 to about 80 percent hydrogen peroxide by weight.

In yet another embodiment of the present invention, useful oxidants in the dihydroxylation process 20 for reacting aryl allyl ethers of the present invention are tertiary organic amine N-oxides. Generally, the organic amine N-oxides used as the oxidizing agent in the α-dihydroxylation process of the present invention may be any organic compounds having at least one N-oxide ($\equiv\text{N}-\text{O}$) 25 functional group. The amine N-oxides useful in the present invention preferably have the following general structure:



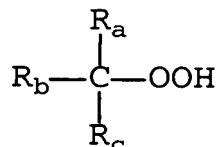
wherein R_a, R_b, and R_c are the same or different; and R_a, R_b, and R_c have from 1 to 12 carbon atoms; and R_a, R_b, and R_c are selected from the group comprising an alkyl group, such as methyl or ethyl; a cycloaliphatic group, such as 5 cyclohexyl; an aromatic group such as phenyl or benzyl; or any combination thereof. A combination of two or more of R_a, R_b, and R_c can also be in the same structural unit such as in the case of a pinanyl group.

Organic amine N-oxides useful in the present 10 invention include, for example, but are not limited to, trimethylamine N-oxide, triethylamine N-oxide, N-methyl morpholine N-oxide, and pyridine N-oxide. Mixtures of organic tertiary amine N-oxides may also be employed in the present invention.

15 The organic tertiary amine N-oxide may be pre-formed prior to its use by, for example, air-oxidation of a corresponding tertiary amine. Alternatively, the organic tertiary amine N-oxides may be formed *in situ*. The *in situ* process for making organic tertiary amine N- 20 oxides is feasible, but is generally more difficult to control than pre-forming the organic tertiary amine N-oxides.

In still another embodiment of the present invention, useful oxidants in the dihydroxylation process 25 for reacting aryl allyl ethers of the present invention are the organic hydroperoxides. Organic hydroperoxides used as the oxidizing agent in the α -dihydroxylaiton process of the present invention may be any organic compounds having at least one hydroperoxy (-OOH) 30 functional group. However, tertiary hydroperoxides are

preferred due to the higher instability and greater safety hazards associated with primary and secondary hydroperoxides. The organic hydroperoxide useful in the present invention preferably has the following general structure:



wherein R_a , R_b , and R_c are the same or different; R_a , R_b , and R_c have from 1 to 12 carbon atoms; and R_a , R_b , and R_c are selected from the group comprising hydrogen; an alkyl group, such as methyl or ethyl; a cycloaliphatic group, such as cyclohexyl; an aromatic group such as phenyl or benzyl; or any combination thereof. A combination of two or more of R_a , R_b , and R_c can also be in the same structural unit such as in the case of a pinanyl group.

Examples of organic hydroperoxides useful in the present invention include tert-butyl hydroperoxide; tert-amyl hydroperoxide; cumene hydroperoxide; ethyl benzene hydroperoxide; cyclohexane hydroperoxide; methyl cyclohexane hydroperoxide; pinane hydroperoxide; tetrahydronaphthalene hydroperoxide; isobutyl benzene hydroperoxide; isopropyl hydroperoxide; and ethyl naphthalene hydroperoxide. It is preferred that the hydroperoxide used is tert-butyl hydroperoxide or tert-amyl hydroperoxide. Mixtures of organic hydroperoxides may also be employed in the present invention.

The organic hydroperoxide may be pre-formed prior to its use by, for example, air-oxidation of a

corresponding alkane or aromatic hydrocarbon. Alternatively, the organic hydroperoxide may be formed *in situ*. The *in situ* process for making organic hydroperoxide is feasible, but is generally more difficult
5 to control than pre-forming the organic hydroperoxide.

In a preferred embodiment, the ratio of the oxidant used for dihydroxylation of the aryl allyl ether is preferably in the range of from about 0.6 mole to about 20 moles of oxidant to 1 equivalent of aryl allyl ether
10 moiety. More preferably, the ratio of oxidant used for dihydroxylation to the aryl allyl ether is in the range of from about 1 mole to about 5 moles of oxidant to 1 equivalent of aryl allyl ether moiety. The most preferred ratio for oxidant used for dihydroxylation of the aryl
15 allyl ether is from about 1 mole to about 2.5 moles of oxidant to 1 equivalent of aryl allyl ether moiety. One equivalent of oxidant is theoretically required to oxidize one equivalent of an aryl mono-allyl ether substrate, but it may be desirable to employ an excess of oxidant to
20 optimize conversion to the α -dihydroxy derivative.

Process Conditions for Catalytic Dihydroxylation Process

The oxidation step to convert aryl allyl ethers to α -dihydroxy derivatives of the present invention may be carried out in a variety of ways known to those skilled in
25 the art and, as outlined generally, for example, in the following publications: M. Beller, et al., Appl. Homogeneous Catal. Organomet. Compd., 2, B. Cornils and W. A. Herrmann, Eds. pp. 1009, (1996); H. C. Kolb, et al., Chem. Rev., 94, pp. 2483, (1994); I. Marko, et al.,

Comprehensive Asymmetric Catal. I-III, E. N. Jacobsen, A. Pfaltz, and H. Yamamoto, Eds., pp. 713, (1999); and V. VanRheenen, et al., Org. Syn., Coll. Vol. VI, pp. 342, (1988); all of which are incorporated herein by reference.

To carry out the catalytic α -dihydroxylation process of the present invention using hydrogen peroxide oxidant, a tertiary amine N-oxide oxidant, or organic hydroperoxide oxidant, the oxidant hydrogen peroxide, amine N-oxide, or organic hydroperoxide may be added to a reactor in one batch together with one or more aryl allyl ethers represented by having Formula I to V. It is preferred to add the hydrogen peroxide, amine N-oxide, or organic hydroperoxide oxidant incrementally to the reactor when a large amount of hydrogen peroxide, amine N-oxide oxidant, or organic hydroperoxide oxidant is used.

In another embodiment, the oxidant such as, for example, hydrogen peroxide, the tertiary amine N-oxide, or organic hydroperoxide can be added concurrently with an aryl allyl ether into a reactor in a continuous fashion.

The temperature of the dihydroxylation process of the present invention should be sufficient to accomplish substantial conversion of the aryl allyl ether to the α -dihydroxy derivative within a reasonably short period of time. It is generally advantageous to carry out the α -dihydroxylation process to achieve as high conversion as possible, preferably at least greater than about 50 percent (%), more preferably at least greater than about 75%, and most preferably at least greater than

about 90%, consistent with reasonable selectivities to the α -dihydroxy derivative. The optimum dihydroxylation process temperature will be influenced by catalyst activity, aryl allyl ether reactivity, reactant concentrations, and type of solvent employed, among other factors. But typically, the dihydroxylation process of the present invention is carried out at a temperature of from about -20 °C to about 150 °C, preferably from about -15 °C to about 100 °C, and more preferably from about -10 °C to about 80 °C.

Preferably, in a dihydroxylation process, reaction times that vary from about 10 minutes to about 48 hours will typically be appropriate, depending upon the above-identified dihydroxylation reaction variables. More preferably, in a α -dihydroxylation process, the reaction time may vary from about 10 minutes to about 24 hours; and most preferably, in a α -dihydroxylation process, the reaction time may vary from about 10 minutes to about 2 hours.

The dihydroxylation process pressure may be atmospheric; sub-atmospheric, for example, from less than about 760 millimeters of mercury to about 5 millimeters of mercury; or super-atmospheric, for example, from about 1 atmosphere to about 100 atmospheres. Generally, it will be desirable to maintain the α -dihydroxylation process components as a liquid phase mixture.

The dihydroxylation process of the present invention may be carried out in a stirred batch, semi-continuous, or continuous manner using any appropriate

type of process vessel or apparatus, provided the reaction mixture is adequately agitated. Thus, the reactants may be combined all at once or sequentially.

After the dihydroxylation process is completed,
5 the α -dihydroxylation process mixture is subjected to separation and purification by known process operations and the excess, unused, organic oxidant, as well as, catalyst, additives, co-catalyst, and co-oxidants may be recovered and recycled, or destroyed and disposed of. For
10 example, once the α -dihydroxylation process reaction has been completed to the desired amount of conversion, the desired α -dihydroxy derivative product may be separated and recovered from the dihydroxylation process mixture using appropriate techniques such as filtration,
15 fractional distillation, extractive distillation, liquid-liquid extraction, solid-liquid extraction, crystallization, or any combination thereof.

In one embodiment of the present invention, the excess oxidant remaining after the dihydroxylation process
20 may be recovered and recycled to the dihydroxylation process or the excess oxidant remaining after the dihydroxylation process may be decomposed by addition of a reducing agent.

The decomposition by-product of an α -
25 dihydroxylation process using an organic hydroperoxide oxidant is a secondary or tertiary alcohol compound of the corresponding organic hydroperoxide oxidant. After isolation from the dihydroxylation reaction mixture, the alcohol decomposition product of the organic hydroperoxide

can be dehydrated and hydrogenate or reacted directly under hydrogenolysis conditions to the corresponding alkane or aromatic hydrocarbon of the organic hydroperoxide oxidant. The alkane or aromatic hydrocarbon 5 product may be reoxidized to the hydroperoxide and recycled to the α -dihydroxylation oxidation process.

Solvents

The dihydroxylation process of the present invention may be carried out optionally in the presence of 10 a solvent. Solvents that may be used in the dihydroxylation process mixture of the present invention include solvents that do not react with the inorganic or organic oxidant, catalyst, additive, co-catalyst, or co-oxidant used in the dihydroxylation process mixture of the 15 present invention, but in which they are at least partially soluble. For example, some solvents, such as dimethylsulfoxide, will react with an organic hydroperoxide, such as tert-butyl hydroperoxide. Solvents which can be used in the present invention include, for 20 example, aliphatic, cycloaliphatic or aromatic hydrocarbon solvents; partially or fully chlorinated or fluorinated, or combinations thereof; aliphatic, cycloaliphatic or aromatic esters, ethers, alcohols, ketones and nitriles; and partially or fully chlorinated or fluorinated 25 aliphatic, cycloaliphatic or aromatic ester, ether, alcohol, ketones, and nitrile solvents; water; and combinations thereof.

Solvents especially useful in the dihydroxylation process include alcohols such as tertiary

butyl alcohol, ketones such as acetone, other non-reactive, water-miscible solvents, and mixtures thereof.

In another embodiment of the present invention, solvents which may be used in the present invention are
5 solvents that may be used under dense phase or supercritical conditions. Such solvents include, for example, but are not limited to, carbon dioxide, ethane, dimethyl ether, and mixtures thereof.

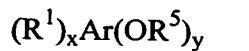
The solvent useful in the present invention is
10 generally employed in an amount of from 0 parts by weight to about 100 parts by weight of solvent per one part of substrate reactant aryl allyl ether. Preferably, the amount of solvent used is from 0 parts to about 25 parts by weight of solvent per one part of substrate reactant
15 aryl allyl ether; and more preferably, the amount of solvent used is from 0 parts to about 10 parts by weight of solvent per one part of substrate reactant aryl allyl ether.

The α -dihydroxy derivatives of the present
20 invention prepared above can be converted into epoxy compounds by various means well-known to those skilled in the art.

Epoxy Compounds

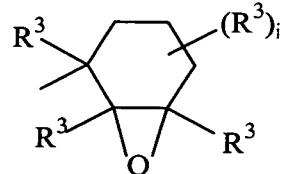
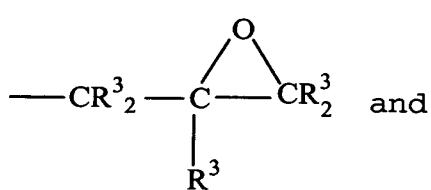
The aryl glycidyl ether epoxy compounds that are
25 made by the process of the present invention are represented by, but not limited to, the structures of the following Formulas XVI-XX:

Formula XVI



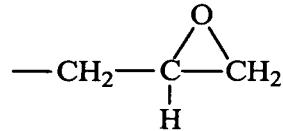
In Formula XVI, x, y, Ar, O and R¹ are as defined previously for Formula I.

5 In Formula XVI, R⁵ is a glycidyl-containing moiety preferably selected from:



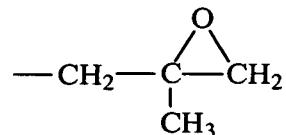
where R³ and i are as defined previously for Formula I.

10 In one embodiment, when R⁵ in Formula XVI above has the following structure:



the glycidyl ether is a "glycidyl ether."

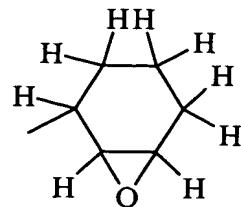
In another embodiment, when R⁵ in Formula XVI above has the following structure:



15

the glycidyl ether is a "methylglycidyl ether."

In yet another embodiment, when R⁵ in Formula XVI above has the following structure:

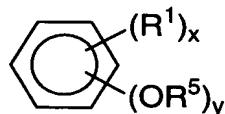


the glycidyl ether is a "cyclohexylglycidyl ether."

5 More specific and preferred examples of epoxy resins that may be prepared according to the present invention are represented by Formulas XVII-XX separately or mixtures of two or more epoxy resins which follow.

10 Examples of mononuclear aryl glycidyl ether epoxy resins that may be prepared according to the present invention are represented by the following Formula XVII:

Formula XVII



15

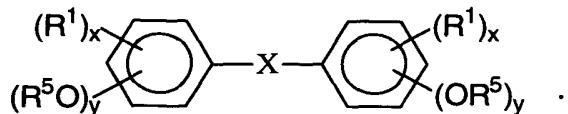
In Formula XVII, x, y, O and R¹ have the same meaning as described above with reference to Formula II. In Formula XVII, R⁵ has the same meaning as described above with reference to Formula XVI.

20 Mononuclear phenols useful as precursors for preparing the above mononuclear aryl glycidyl ether epoxy resins of the present invention are, for example, 2-methylphenol; 4-methylphenol; 4-methoxyphenol; 2,6-

dimethylphenol; 2,6-diisopropylphenol; 2,6-dibromophenol; 1,2-, 1,3- and 1,4-dihydroxybenzene; 1,4-, 1,5- and 2,6-dihydroxynaphthalene; and mixtures thereof.

Other examples of aryl glycidyl ethers prepared
5 by the process of the present invention are dinuclear aryl glycidyl ether epoxy resins that are represented by the following Formula XVIII:

Formula XVIII



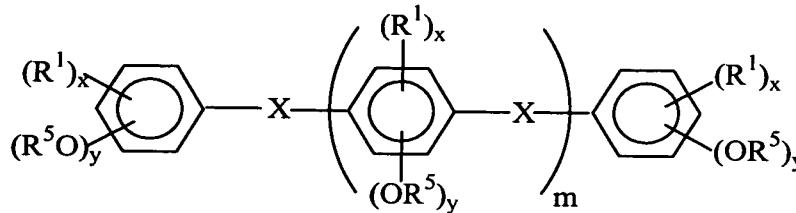
In Formula XVIII, x, y, X, O and R¹ have the same meaning as described above with reference to Formula III. In Formula XVIII, R⁵ has the same meaning as described above with reference to Formula XVI.

Phenols useful for making the epoxy resins of
15 Formula XVIII include, for example, 4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo-4,4'-dihydroxybiphenyl; bis(4-hydroxyphenyl)methane; bis(4-hydroxyphenyl)sulfone; 2,2-bis(3,5-dibromo-4-hydroxyphenyl)isopropylidene; 2,2-bis(4-hydroxyphenyl)isopropylidene; bisphenol K; 9,9-bis(4-hydroxyphenyl)fluorene; 4,4'-dihydroxy- α -methylstilbene; 1,3-bis(4-hydroxylphenyl)adamantane; and mixtures thereof.

Other examples of aryl glycidyl ethers prepared
25 by the process of the present invention are multi-nuclear

aryl glycidyl ether epoxy resins that are represented by the following Formula XIX:

Formula XIX

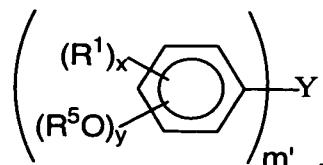


5 In Formula XIX, x , y , X , O , R^1 and m are as described above for Formula IV. In Formula XIX, R^5 has the same meaning as described above with reference to Formula XVI.

10 Phenols useful for making the epoxy resins of Formula XIX include, for example, phenol-formaldehyde novolac (functionality greater than 2); o-cresol-formaldehyde novolac (functionality greater than 2); phenol-dicyclopentadienyl novolac (functionality greater than 2); naphthol-formaldehyde novolac (functionality greater than 2); and mixtures thereof.

15 Still other examples of aryl glycidyl ethers prepared by the process of the present invention are multi-nuclear aryl glycidyl ether epoxy resins that are represented by the following Formula XX:

Formula XX



In Formula XX, x, y, Y, O, R¹ and m' are the same as previously described above for Formula V. In Formula XXI, R⁵ has the same meaning as described previously with reference to Formula XVI.

5 Phenols useful for making the epoxy resins of Formula XX include, for example, tris(4-hydroxyphenyl) methane; tris(3,5-dimethyl-4-hydroxyphenyl)methane; 1,1,2,2-tetrakis(4-hydroxyphenyl)ethane; and mixtures thereof.

10 Examples of preferred aryl glycidyl ether epoxy resins of the present invention include, for example, 2-methylphenol glycidyl ether; 4-methylphenol glycidyl ether; 4-methoxyphenol glycidyl ether; 2,6-dimethylphenol glycidyl ether; 2,6-diisopropylphenol glycidyl ether; 2,6-15 dibromophenol glycidyl ether; 1,2-, 1,3- and 1,4-dihydroxybenzene diglycidyl ethers; 1,4-, 1,5- and 2,6-dihydroxynaphthalene diglycidyl ethers; 4,4'-(3,3',5,5'-tetramethyl)bisphenol A diglycidyl ether; 4,4'-(3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo)bisphenol A diglycidyl ether; 4,4'-(3,3',5,5'-tetramethyl)bisphenol F diglycidyl ether; 4,4'-(3,3',5,5'-tetramethyl)biphenol diglycidyl ether; 4,4'-biphenol diglycidyl ether; 4,4'-(3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo)biphenol diglycidyl ether; 4,4'-bisphenol F diglycidyl ether; 4,4'-bisphenol 25 sulfone diglycidyl ether; 4,4'-(3,3',5,5'-tetrabromo)bisphenol A diglycidyl ether; 4,4'-bisphenol A diglycidyl ether; 4,4'-bisphenol K diglycidyl ether; 9,9-bis(4-hydroxyphenyl)fluorene diglycidyl ether; 4,4'-dihydroxy- α -methylstilbene diglycidyl ether; 1,3-bis(4-hydroxyphenyl)adamantane diglycidyl ether; phenol-30 formaldehyde novolac glycidyl ether (functionality >2); o-

cresol-formaldehyde novolac glycidyl ether (functionality >2); phenol-dicyclopentadienyl novolac glycidyl ether (functionality >2); naphthol-formaldehyde novolac glycidyl ether (functionality >2); trisphenylol methane triglycidyl ether; tris(3,5-dimethyl-4-hydroxyphenyl)methane triglycidyl ether; 1,1,2,2-tetraphenylol ethane tetraglycidyl ether; and mixtures thereof.

The epoxy resins described above may be prepared by various processes utilizing the α -dihydroxy derivatives of the present invention including for example via an intermediate such as (1) a carbonate such as described in U.S. Patent No. 6,005,063 and in WO 99/09020, both of which are incorporated herein by reference, or (2) an α -halohydrin intermediate such as described in U.S. Patent No. 6,001,945, incorporated herein by reference. The epoxy resin of the present invention is preferably produced by first forming an α -halohydrin intermediate from an allyl ether, and then converting the α -halohydrin intermediate into the epoxy compound.

20 α -Halohydrin Intermediates

The present invention includes a process for manufacturing an α -halohydrin intermediate from an α -dihydroxy derivative. The α -halohydrin intermediate is then used to make epoxy resins.

25 Generally, the process of the present invention for manufacturing the α -halohydrin intermediate includes converting an α -dihydroxy derivative to the α -halohydrin intermediate by a halide substitution process using a hydrogen halide and a catalytic amount of a carboxylic

acid or carboxylic acid ester; or by a halide substitution process using a hydrogen halide and a carboxylic acid ester as solvent. Then, the α -halohydrin intermediate can be used to make epoxy resins by well-known techniques in the industry, such as, for example, by a ring-closing epoxidation reaction of the α -halohydrin intermediate with a base. More preferably, the epoxy resins which can be prepared by the process of the present invention include, for example, bisphenol A (bis A) diglycidyl ether epoxy resin also known as BADGE.

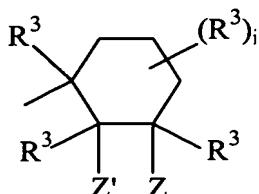
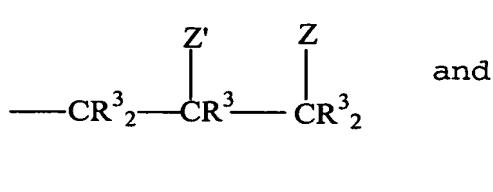
The α -halohydrin intermediates prepared in accordance with the process of the present invention are represented for example by, but not limited to, the structures of the following Formulas XXI-XXV. A preferred class of α -halohydrin intermediates useful in the present invention is generically represented for example by the following Formula XXI:

Formula XXI



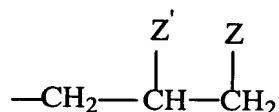
In Formula XXI, x, y, Ar, O, and R¹ are as defined in Formula I.

In Formula XXI, R⁶ is an α -halohydrin propyl-containing moiety preferably selected from:



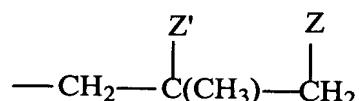
where Z is a halogen atom such as chlorine, bromine or iodine; and Z' is a hydroxyl group. The positions of Z and Z' may be interchanged. R³ and i in Formula XXI are as previously defined in Formula I.

5 In one embodiment, when R⁶ in Formula I above is the following structure:



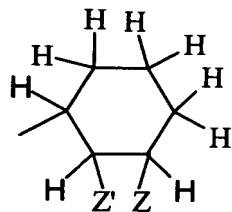
the α -halohydrin is a 3-halo-2-hydroxy-1-propyl moiety-containing derivative; or in such derivative, the hydroxy and halo groups may be interchanged to form a 2-halo-3-hydroxy-1-propyl moiety-containing derivative.

In another embodiment, when R⁶ in Formula XXI above is the following structure:



15 the α -halohydrin is a 3-halo-2-hydroxy-2-methyl-1-propyl moiety-containing derivative; or in such derivative, the hydroxy and halo groups may be interchanged to form a 2-halo-3-hydroxy-2-methyl-1-propyl moiety-containing derivative.

20 In yet another embodiment, when R⁶ in Formula XXI above is the following structure:

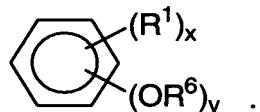


the α -halohydrin is a 3-halo-2-hydroxy-1-cyclohexyl moiety-containing derivative; or in such derivative, the hydroxy and halo groups may be interchanged to form a 2-halo-3-hydroxy-1-cyclohexyl moiety-containing derivative. In both derivatives, the propyl moiety is contained in the cyclohexyl ring structure.

More specific and preferred examples of α -halohydrin intermediates useful in the present invention are represented by Formulas XXII-XXV separately or as mixtures of two or more α -halohydrin intermediates of Formulas XXII-XXV which follow.

Examples of mononuclear aromatic α -halohydrin intermediates useful in the present invention are represented for example by the following Formula XXII:

Formula XXII

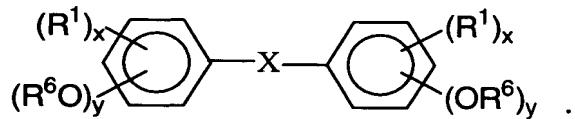


In Formula XXII, x , y , O , and R^1 have the same meaning as described above with reference to Formula II. In Formula XXII, R^6 has the same meaning as described above with reference to Formula XXI. α -Halohydrin intermediates of Formula XXII can be prepared from phenolic compounds or

aromatic hydroxyl group-containing precursors, such as, for example, 2-methylphenol; 4-methylphenol; 4-methoxyphenol; 2,6-dimethylphenol; 2,6-diisopropylphenol; 2,6-dibromophenol; 1,2-dihydroxybenzene; 1,3-
5 dihydroxybenzene; 1,4-dihydroxybenzene; 1,4-, 1,5- and 2,6-dihydroxynaphthalene; and mixtures thereof.

Other examples of α -halohydrin intermediates useful in the present invention are binuclear aromatic α -halohydrin intermediates which are represented, for
10 example, by the following Formula XXIII:

Formula XXIII



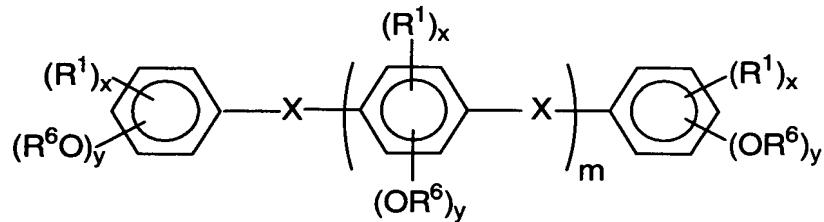
In Formula XXIII, x, y, X, O and R¹ have the same meaning as described above with reference to Formula III.
15 In Formula XXIII, R⁶ has the same meaning as described above with reference to Formula XXI.

Precursors useful for making the α -halohydrin intermediates of Formula XXIII include, for example, 4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-4,4'-dihydroxybiphenyl; 3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo-4,4'-dihydroxybiphenyl; bis(4-hydroxyphenyl)methane; bis(4-hydroxyphenyl)sulfone; 2,2-bis(3,5-dibromo-4-hydroxyphenyl)isopropylidene; 2,2-bis(4-hydroxyphenyl)isopropylidene; bisphenol K; 9,9-bis(4-hydroxyphenyl)fluorene; 4,4'-dihydroxy- α -methylstilbene; 1,3-bis(4-hydroxylphenyl)adamantane; and mixtures thereof.

Other examples of α -halohydrin intermediates useful in the present invention are multinuclear aromatic α -halohydrin intermediates which are represented, for example, by the following Formula XXIV:

5

Formula XXIV

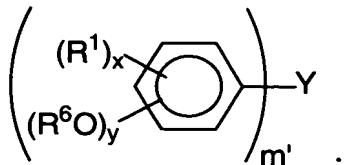


In Formula XXIV, x , y , O , X , R^1 and m have the same meaning as has been previously described above in Formula III. In Formula XXIV, R^6 has the same meaning as described above with reference to Formula XXI.

Precursors useful for making the α -halohydrin intermediates of Formula XXIV include, for example, phenol-formaldehyde novolac (functionality greater than 2); o-cresol-formaldehyde novolac (functionality greater than 2); phenol-dicyclopentadienyl novolac (functionality greater than 2); naphthol-formaldehyde novolac (functionality greater than 2); and mixtures thereof.

Other examples of α -halohydrin intermediates useful in the present invention are multi-nuclear aromatic 20 α -halohydrin intermediates which are represented, for example, by the following Formula XXV:

Formula XXV



In Formula XXV, x, y, O, R¹, Y and m' have the same meaning as has been previously described above in
5 Formula V. In Formula XXV, R⁶ has the same meaning as described previously with reference to Formula XXI.

Precursors useful for making the α -halohydrin intermediates of Formula XXV include, for example, tris(4-hydroxyphenyl)methane; 1,1,1-tris(3,5-dimethyl-4-hydroxyphenyl)methane; 1,1,2,2-tetrakis(4-hydroxyphenyl)ethane; and mixtures thereof.
10

Preferably, the α -halohydrin intermediates of the present invention, include for example (3-chloro-2-hydroxy-1-propyl) ether of 2-methylphenol; (3-chloro-2-hydroxy-1-propyl) ether of 4-methylphenol; (3-chloro-2-hydroxy-1-propyl) ether of 4-methoxyphenol; (3-chloro-2-hydroxy-1-propyl) ether of 2,6-dimethylphenol; (3-chloro-2-hydroxy-1-propyl) ether of 2,6-diisopropylphenol; (3-chloro-2-hydroxy-1-propyl) ether of 2,6-dibromophenol;
15 bis(3-chloro-2-hydroxy-1-propyl) ether of 1,2-, 1,3- and 1,4-dihydroxybenzene; bis(3-chloro-2-hydroxy-1-propyl) ether of 1,4-, 1,5- and 2,6-dihydroxynaphthalene; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-(3,3',5,5'-tetramethyl)bisphenol A; bis(3-chloro-2-hydroxy-1-propyl)
20 ether of 4,4'-(3,3',5,5'-tetramethyl-2,2',6,6'-tetrabromo)bisphenol A; bis(3-chloro-2-hydroxy-1-propyl)ether of 4,4'-(3,3',5,5'-tetramethyl)bisphenol F;
25

bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-(3,3'5,5'-tetramethyl)biphenol; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-biphenol; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-(3,3'5,5'-tetramethyl-2,2',6,6'-tetrabromo)biphenol; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-bisphenol F; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-bisphenol sulfone; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-(3,3',5,5'-tetrabromo)bisphenol A; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-bisphenol A; bis(3-chloro-2-hydroxy-1-propyl)ether of 4,4'-bisphenol K; bis(3-chloro-2-hydroxy-1-propyl) ether of 9,9-bis(4-hydroxyphenyl)fluorene; bis(3-chloro-2-hydroxy-1-propyl) ether of 4,4'-dihydroxy- α -methylstilbene; bis(3-chloro-2-hydroxy-1-propyl) ether of 1,3-bis(4-hydroxyphenyl)adamantane; (3-chloro-2-hydroxy-1-propyl) ether of phenol-formaldehyde novolac (functionality >2); (3-chloro-2-hydroxy-1-propyl) ether of o-cresol-formaldehyde novolac (functionality >2); (3-chloro-2-hydroxy-1-propyl) ether of phenol-dicyclopentadienyl novolac (functionality >2); (3-chloro-2-hydroxy-1-propyl)ether of naphthol-formaldehyde novolac (functionality >2); tri(3-chloro-2-hydroxy-1-propyl) ether of trisphenylol methane; tri(3-chloro-2-hydroxy-1-propyl) ether of tris(3,5-dimethyl-4-hydroxyphenyl)methane; tetra(3-chloro-2-hydroxy-1-propyl) ether of 1,1,2,2-tetraphenylol ethane; and mixtures thereof.

In addition, the chloro and hydroxyl groups in the above 3-chloro-2-hydroxyl-1-propyl moiety-containing derivatives may be interchanged to form 3-hydroxy-2-chloro-1-propyl moiety-containing derivatives.

The α -halohydrin intermediates of the present invention comprise from about 10 to about 100 percent, more preferably from about 25 to about 100 percent, most preferably from about 50 to about 100 percent, of the 5 total weight of one, or more than one, component(s) as illustrated in the above Formulas XXI-XXV.

The α -halohydrin intermediates of the present invention, for example as illustrated in the above Formulas XXI-XXV, are prepared by first obtaining an α -dihydroxy derivative and then converting the α -dihydroxy derivative to the α -halohydrin intermediate using a halide substitution process. More particularly, the α -halohydrin intermediates of the present invention are prepared by reacting the following components: (A) an α -dihydroxy derivative, (B) a hydrogen halide, (C) a catalytic amount of (i) a carboxylic acid or (ii) a carboxylic acid ester, in the presence of (D) a carboxylic acid ester solvent, and optionally, in the presence of (E) a non-carboxylic acid ester solvent.

20 The hydrogen halide, Component (B), useful in manufacturing the α -halohydrin intermediates of the present invention may include, for example, hydrogen chloride, hydrogen bromide or hydrogen iodide.

25 The amount of hydrogen halide, Component (B), useful in manufacturing the α -halohydrin intermediates of the present invention should be sufficient to ensure substantially complete conversion of the α -dihydroxy derivative to the α -halohydrin intermediate. The amount of hydrogen halide used is generally from about 0.50 mole

to about 20 moles of hydrogen halide relative to the equivalents of α -dihydroxy moieties being reacted in the α -dihydroxy derivative; preferably from about 0.75 mole to about 10 moles of hydrogen halide relative to the 5 equivalents of α -dihydroxy moieties being reacted in the α -dihydroxy derivative; and more preferably from about 0.95 mole to about 5 moles of hydrogen halide relative to the equivalents of α -dihydroxy moieties being reacted in the α -dihydroxy derivative.

10 The hydrogen halide may be added neat to the reaction as a liquid or as a gas. When added to the reaction as a gas, the hydrogen halide may be added as a continuous stream of gas. The hydrogen halide may also be dissolved in a solvent, such as those described in
15 reference to Component (E) below, and added to the reactor as a solution. When an amount of halogen halide in excess of the stoichiometric amount necessary to ensure complete conversion of the of α -dihydroxy derivative is used, the excess amount may be removed from the reaction mixture by
20 washing with water or careful neutralization with a base. It is preferred to recover and recycle the excess hydrogen halide by distilling the hydrogen halide from the reaction mixture.

25 The carboxylic acid, Component (C), useful in manufacturing the α -halohydrin intermediate of the present invention is a carboxylic acid having from 1 to 20 carbon atoms. The carboxylic acid, Component (C), useful in manufacturing the α -halohydrin intermediate of the present invention may include, for example monocarboxylic acids,
30 such as, acetic acid, propionic acid, propenoic acid,

hexanoic acid, cyclohexanoic acid, benzoic acid; dicarboxylic acids, such as, 1,4-butanedioic acid, 1,6-hexanedioic acid, 1,2-cyclohexandioic acid; or multifunctional carboxylic acid wherein the carboxylic
5 acid groups are attached to an inorganic, an organic, or a hybrid inorganic-organic support, such as a weak acid, crosslinked, ion exchange resin; and mixtures thereof.

The amount of carboxylic acid, Component (C), used as catalyst in the halide substitution process may
10 vary from about 0.05 mole % to about 50 mole % of carboxylic acid relative to the moles of α -dihydroxy derivative being reacted; preferably, the amount of carboxylic acid used may vary from about 0.05 mole % to about 25 mole % of carboxylic acid relative to the moles
15 of α -dihydroxy derivative being reacted; and most preferably, the amount of carboxylic acid used may vary from about 0.05 mole % to about 10 mole % of carboxylic acid relative to the moles of α -dihydroxy derivative being reacted.

20 The carboxylic acid ester, Component (C), useful in manufacturing the α -halohydrin intermediate of the present invention is an ester of a monocarboxylic acid or dicarboxylic acid having 1 to 20 carbon atoms. The monocarboxylic acid or dicarboxylic acid moiety of the
25 carboxylic acid ester may contain, for example, one or more heteroatoms selected from the group comprising O, N, S, Si, B, P, Cl and F. The monocarboxylic acid or dicarboxylic acid of the carboxylic acid ester is selected, for example, from the group comprising acetic acid, propionic acid, propenoic acid, 2-methylpropenoic acid, butanoic acid, 1,4-butanedioic acid, hexanoic acid,

1,6-hexanedioic acid, cyclohexanoic acid, 1,2-cyclohexandioic acid, benzoic acid, and mixtures thereof.

The carboxylic acid ester, Component (C) and (D), useful in manufacturing the α -halohydrin intermediate of the present invention is, for example, the ester of an aliphatic mono alcohol, diol, or triol having 1 to 12 carbon atoms, and the hydroxyl group(s) of the aliphatic mono alcohol, diol, or triol is a primary or secondary hydroxyl group. The aliphatic mono alcohol, diol, or triol moiety of the carboxylic acid ester may contain, for example, one or more heteroatoms selected from the group comprising O, N, S, Si, B, P, Cl and F. The aliphatic mono alcohol, diol, or triol is selected, for example, from the group comprising methanol, ethanol, propanol, isopropanol, 1-butanol, 2-butanol, isobutanol, cyclohexanol, benzyl alcohol, 1-methoxy-2-propanol, 1-ethoxy-2-propanol, ethylene glycol, diethylene glycol, propylene glycol, dipropylene glycol, glycerine, trimethylolpropane, and mixtures thereof.

The carboxylic acid ester, Component (C), useful in manufacturing the α -halohydrin intermediate of the present invention is selected, for example, from the group comprising ethyl acetate, propyl acetate, isopropyl acetate, 1-methoxy-2-propanol acetate, butyl acetate, ethylene glycol diacetate, propylene glycol diacetate, trimethylolpropane triacetate, and mixtures thereof.

The amount of carboxylic acid ester Component (C), used as catalyst in the halide substitution process to convert the α -dihydroxy derivative to the α -halohydrin intermediate may vary from about 0.05 mole % to about 50

mole % of carboxylic acid ester relative to the moles of α -dihydroxy derivative being reacted; preferably, the amount of carboxylic acid ester used may vary from about 0.05 mole % to about 25 mole % of carboxylic acid ester

5 relative to the moles of α -dihydroxy derivative being reacted; and most preferably, the amount of carboxylic acid ester used may vary from about 0.05 mole % to about 10 mole % of carboxylic acid ester relative to the moles of α -dihydroxy derivative being reacted.

10 The amount of carboxylic acid ester, Component (D), used as a solvent in the halide substitution process to convert the α -dihydroxy derivative to the α -halohydrin intermediate is from about 0.01 to about 100 parts (on a weight basis) of carboxylic acid ester to 1 part α -dihydroxy derivative. More preferably, the amount of carboxylic acid ester, Component (D), used as a solvent in the halide substitution process to convert the α -dihydroxy derivative to the α -halohydrin intermediate is from about 0.01 to about 10 parts (on a weight basis) of carboxylic acid ester to 1 part α -dihydroxy derivative; and most preferably, the amount of carboxylic acid ester, Component (D), used as a solvent in the halide substitution process to convert the α -dihydroxy derivative to the α -halohydrin intermediate is from about 0.01 to about 5 parts (on a weight basis) of carboxylic acid ester to 1 part α -dihydroxy derivative

30 The non-carboxylic acid ester solvent, optional Component (E), which may be used in the above process for making the α -halohydrin intermediate may be, but is not limited to, aliphatic and cyclic hydrocarbons such as

pentane, hexane, octane, *iso*-octane, cyclohexane and cyclooctane; aromatic hydrocarbons such as benzene, toluene and xylene; chlorinated solvents such as, for example, methylene dichloride, tetrachloroethane and 5 chlorobenzene; aprotic solvents such as acetone, methyl *iso*-butyl ketone, acetonitrile, dimethoxyethane, 2,2'-dimethoxy diethyl ether, dioxane, dimethyl sulfoxide and 1-methoxy-2-acetoxypropane; protic solvents such as, for example, ethanol, 1-propanol, isopropyl alcohol, 1- 10 butanol, 2-butanol, *tert*-butanol, 1-pentanol, *tert*-amyl alcohol, 1-hexanol, cyclohexanol and 1-methoxy-2-hydroxypropane; partially or fully fluorinated derivatives thereof; and any combination thereof. Optionally, the solvent may be used with or without the presence of water.

15 When protic alcohol solvents are optionally used, it is preferred that the alcohol solvents are secondary or tertiary alcoholic solvents, such as isopropyl alcohol, 2-butanol, *tert*-butanol, *tert*-amyl alcohol and 1-methoxy-2-hydroxypropane; partially or fully 20 fluorinated derivatives thereof; and any combination thereof.

In general, the amount of the non-carboxylic acid ester solvent, optional Component (E), used in the present invention may be a ratio of from 0 to about 50 25 parts (on a weight basis) of a single solvent or a mixture of two or more solvents to 1 part α -dihydroxy derivative. A more preferred solvent to α -dihydroxy derivative ratio is from 0 to about 10 parts solvent per 1 part α -dihydroxy derivative. The most preferred solvent to α -dihydroxy

derivative ratio is from 0 to about 5 parts solvent per 1 part α -dihydroxy derivative.

The temperature in the above reaction process for halide substitution of the α -dihydroxy derivative is generally from about 0 °C to about 150 °C; preferably from about 20 °C to about 130 °C; and more preferably from about 40 °C to about 110 °C. At a temperature below 0 °C, the reaction is not complete. At a temperature above about 150 °C, undesirable chlorination reactions may take place.

The pressure used in the above reaction process for halide substitution of the α -dihydroxy derivative for manufacturing the α -chlorohydrin intermediate may be atmospheric, subatmospheric or superatmospheric. The pressure is not critical and may be determined by parameters such as type of hydrogen halide used, reaction temperature, type of solvent used or the solvent azeotrope boiling point.

The halide substitution of α -dihydroxy derivative to make the α -halohydrin intermediate can be carried out in a batch or in a continuous reaction mode. In a batch reaction, the α -dihydroxy derivative is optionally dissolved in a solvent, and the carboxylic acid, or the carboxylic acid ester, and the hydrogen halide are added to the reactor. In a batch process, it is highly desirable to run the reaction under pressure to maintain the hydrogen halide in the solution phase. When the batch reaction using hydrogen halide in solution phase is completed, the excess hydrogen halide and the carboxylic acid, or the carboxylic acid ester, may be

removed from the reaction mixture by washing with water, by careful neutralization with a base, or by distillation. Or, the excess hydrogen halide and the carboxylic acid or the carboxylic acid ester may be recovered and recycled as
5 described below.

In some instances, for example when using hydrogen chloride gas, it may be beneficial to purge the gas continuously through a reactor while efficiently mixing or agitating the reaction mixture in the reactor.
10 In this process, the hydrogen chloride gas exiting the reactor is collected and recycled to the reactor.

In a continuous halide substitution process, the α -dihydroxy derivative and the carboxylic acid or carboxylic acid ester can optionally be mixed with a
15 solvent and then intimately mixed with hydrogen halide as the carboxylic acid or carboxylic acid ester and α -dihydroxy derivative and optionally solvent is fed into a reactor. The reactors which may be used are well known in the art, for example, the reactor may be of a tubular
20 design. After the reaction product leaves the reactor, the reaction product may pass through a series of purification steps. For example, in one embodiment when a solvent and a carboxylic acid are used and the solvent used boils at a lower temperature than the carboxylic
25 acid, the reaction product may be: first, distilled to remove excess hydrogen halide where the hydrogen halide may then be recycled to the halide substitution reactor; second, distilled to remove the solvent, wherein the solvent may then be recycled to a halide substitution
30 unit; and third, distilled to remove the carboxylic acid

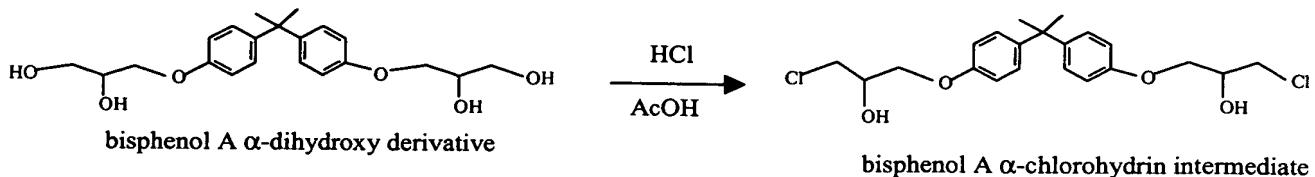
wherein the carboxylic acid product may then be recycled to the halide substitution unit.

In another second embodiment, when a solvent and a carboxylic acid are used, and the solvent used boils at 5 a higher temperature than the carboxylic acid, the reaction product may be: first, distilled to remove the hydrogen halide wherein the hydrogen halide may then be recycled to the halide substitution reactor; and second, distilled to remove the carboxylic acid. In the second 10 embodiment above, the solvent may optionally be removed for example by distillation, or the solvent need not be removed, wherein the solvent is carried forward as a solvent for a subsequent epoxidation step. The distillation steps described above may be carried out at 15 atmospheric pressure, under subatmospheric pressure or under superatmospheric pressure as is well known in the art.

It is highly desirable and preferred to carry out the above processes whereby the α -halohydrin 20 intermediate can be converted to the epoxy resin without additional purification.

The halide substitution of the α -dihydroxy derivative to make the α -halohydrin intermediate of the present invention is illustrated by the following reaction 25 sequence, Reaction Sequence (IV), which shows the chloride substitution of an α -dihydroxy derivative. More specifically, Reaction Sequence (IV) shows the chloride substitution of an α -dihydroxy derivative to synthesize an α -chlorohydrin intermediate of the present invention.

Reaction Sequence (IV)



The α-halohydrin intermediate of the present invention described above, can be converted to the epoxy resin by standard procedures well known to those skilled in the art using bases such as sodium hydroxide, calcium hydroxide, potassium hydroxide, sodium carbonate or mixtures thereof. The epoxidation procedures may be run with a solvent or mixture of solvents, or without solvent.

5 The epoxidation procedures are typically run at elevated temperatures which may vary from about 10 °C to about 130 °C. The epoxidation procedures may be run under atomospheric or under subatomospheric pressure.

The epoxidation procedures may also be run under conditions that do not remove the water which is introduced with the base and which forms in the reaction, or the epoxidation procedures may be run under conditions that remove the water under azeotropic conditions. It is desired to run the epoxidation procedures under conditions that remove water by azeotropic distillation in order to produce epoxy resins having higher epoxide content. The epoxidation procedures may be run including phase transfer catalysts, for example, such as the same phase transfer catalysts described previously.

25 The epoxidation procedures may be carried out as a batch reaction wherein the base may be added in one part initially, added intermittently or added continuously.

The epoxidation procedure may also be carried out as a continuous reaction wherein the α -halohydrin intermediate, the base, the solvent and optionally the phase transfer catalyst are added simultaneously and continuously to a reactor. When the epoxidation procedure is carried out as a continuous reaction, the reactor may be a single, one-stage reactor or the reactor may be a complex reactor having multiple stages. Such epoxidation procedures, including post-treatment procedures for reducing chloride content in epoxy resins, are generally taught in U.S. Patent Nos. 4,499,255; 4,778,863; 4,785,061; and 5,028,686; all of which are incorporated herein by reference.

With reference back to the α -dihydroxy derivative, Component (A) above, the α -dihydroxy derivative is preferably prepared by reaction of a phenolic compound or a mixture of phenolic compounds with an allylation agent.

When the α -dihydroxy derivative, Component (A), is prepared by the above process and such process is combined with the above-described process for preparing an α -halohydrin intermediate from the α -dihydroxy derivative and with a process for making an epoxy resin from the α -halohydrin, generally, the process of the present invention for making phenol-based epoxy resins may be illustrated by the following four-step process which is one embodiment of the present invention:

Step 1: Preparing an aryl allyl ether by reacting a phenolic compound or a mixture of phenolic compounds with an allylation agent;

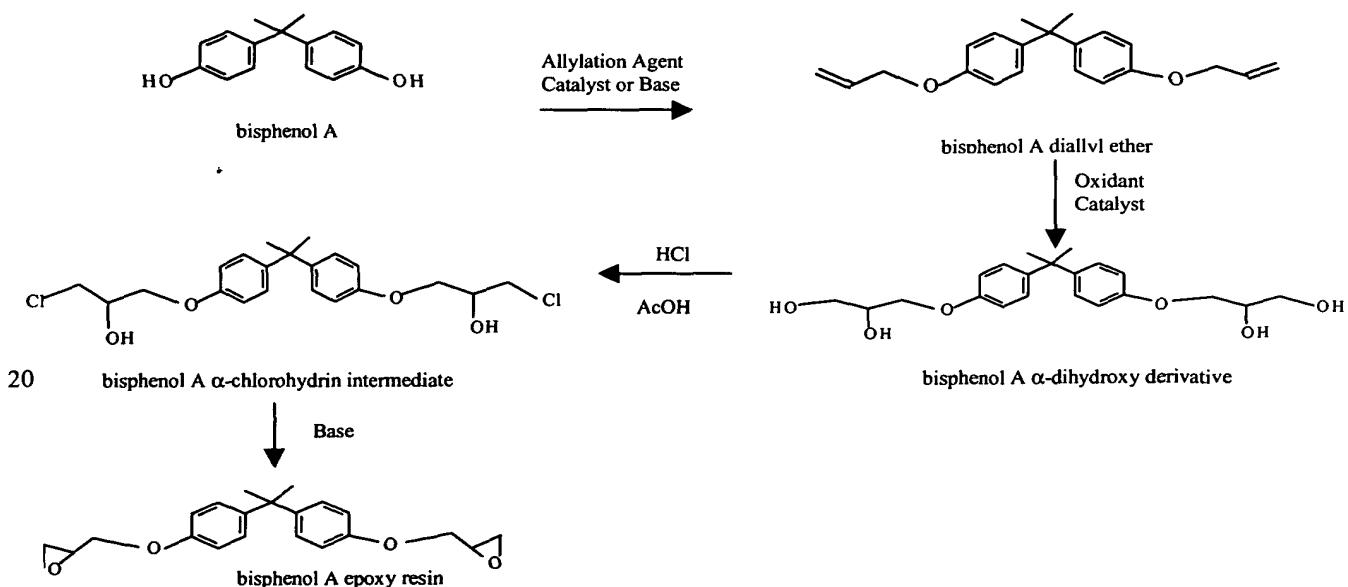
Step 2: Converting the aryl allyl ether of Step 1 above to an α -dihydroxy derivative;

Step 3: Halide substituting the α -dihydroxy derivative of Step 2 above to manufacture an α -halohydrin intermediate; and

Step 4: Epoxidizing the α -halohydrin intermediate of Step 3 above by a ring-closure process using a base to convert the α -halohydrin intermediate of Step 3 to a phenol-based epoxy resin.

In one embodiment of the present invention, the above four-step process may be more specifically illustrated by the following general reaction sequence, Reaction Sequence (V), showing the manufacture of bisphenol A epoxy resin. More specifically, Reaction Sequence (V) shows the conversion of an aryl allyl ether to bisphenol A epoxy resin via the bis(α -chlorohydrin) intermediate made from an bis(α -dihydroxy) derivative.

Reaction Sequence (V)



The epoxy resins prepared in the present invention may be used in various applications including for example, coatings, such as water-borne and solvent-borne coatings, can and coil coatings, powder coatings, 5 industrial and marine protective coatings; adhesives; sealants; composites; and electrical applications, such as electrical laminates and electronic encapsulation.

Example 1

A. Conversion of bisphenol A to bisphenol A diallyl ether

10 Bisphenol A diallyl ether was synthesized as described in U.S. Patent No. 4,740,330. In a four-necked reactor, equipped with a condenser, stirrer, thermometer with temperature controller, and an addition funnel, were added 800 mL of bis-(2-methoxy ethyl) ether (diglyme), 400
15 mL of dimethyl sulfoxide (DMSO), 228 g (1 mole) bisphenol-A, and 284 g (4 moles) of 85% KOH at ambient temperature (~25 °C). The mixture was stirred and heated to 35-40 °C, and the addition of 304 g (4 moles) of allyl chloride was begun. This reaction was exothermic and was controlled at
20 less than 45 °C by controlling the allyl chloride addition rate. The allyl chloride was added over a 4-hour period, and the reaction was continued at 45 °C for an additional 12 hours to convert the bisphenol-A into diallyl ether.
The reaction mixture was cooled to ambient temperature and
25 filtered to remove salts formed in the reaction. The filtrate was mixed with 1000 mL of 50:50 (volume:volume) methyl ethyl ketone-toluene mixture and washed four times with 200 mL portions of water. The solvents were removed from the diallyl product by rotary evaporation first at
30 50-60 °C and 120 mmHg and then at 120-130 °C at 10 mmHg

until gas chromatography (GC) showed all the diglyme and DMSO had disappeared. The yield was 235 g (76% yield) of a light yellow product, bis A diallyl ether, with greater than 95% purity as determined by GC.

5 B. Conversion of bisphenol A diallyl ether to the bis(α -dihydroxy) derivative, bis(2,3- α -dihydroxypropyl)ether of 4,4'-bisphenol A

To a 100-mL, round-bottom flask, were added 1.005 g of bisphenol A diallyl ether from Part A above 10 mL of H₂O, 10 mL of tert-butanol and 1.78 mL of N-methyl morpholine N-oxide (50 wt% aqueous, 1.3 molar equivalents). The resulting reaction mixture was stirred at room temperature and then 0.02 g of K₂OsO₄·2H₂O (2 mol%) was added to the reaction mixture. The reaction mixture was stirred for 43 hours until all the starting material was reacted as determined by thin layer chromatography. Then 0.5 g of Na₂SO₃ and 0.5 g of diatomaceous earth were added to the reaction mixture. The reaction mixture was stirred an additional 1 hour and then filtered. The filtrate was extracted with 3 volumes of ethyl acetate. The resulting extracts were combined and dried over K₂CO₃ and Na₂SO₄, filtered, rotary evaporated, and dried under vacuum. The resulting white solid was analyzed by ¹H NMR spectroscopy and contained 97 mol% of the bis(α -dihydroxy) derivative of bisphenol A diallyl ether and ca. About 3% of α -dihydroxy derivative of bisphenol A monoallyl ether. The white solid (1.052 g; 94% yield) was column chromatographed using a 1 inch by 9 inch silica gel column using ethyl acetate then acetone as the eluant system. Two fractions were isolated: a first fraction, 0.022 g (2.8%), and a second fraction, 0.761 g (97.2%). The

fractions were analyzed by ^1H NMR spectroscopy. The first fraction was the α -dihydroxy derivative of bisphenol A monoallyl ether derived from the monoallyl ether present as an impurity in the starting material. The second 5 fraction was the desired bis(α -dihydroxy) derivative of bisphenol A, bis(2,3- α -dihydroxypropyl)ether of 4,4'-bisphenol A.

10 C. Conversion of bisphenol A diallyl ether to the bis(α -dihydroxy) derivative, bis(2,3- α -dihydroxypropyl)ether of 4,4'-bisphenol A

To a 500-mL, round-bottom flask were added 10.30 g of bisphenol A diallyl ether from Part A above, 100 mL of H_2O , 100 mL of tert-butanol and 15.2 mL of N-methyl morpholine N-oxide (50 wt% aqueous, 1.2 molar equivalents). The resulting reaction mixture was stirred at room temperature and 0.231 g of $\text{K}_2\text{OsO}_4 \cdot 2\text{H}_2\text{O}$ (2 mol%) was added to the reaction mixture. The reaction mixture was allowed to stir for 18 hours. Then, 1.1 g of Na_2SO_3 and 1-2 g of diatomaceous earth were added to the reaction 15 mixture. The reaction mixture was allowed to stir for an additional 1 hour and then filtered. The filtrate was saturated with NaCl , brought to a pH of 1 with concentrated HCl , and then extracted with 4 volumes of ethyl acetate. The resulting extracts were combined and 20 dried over K_2CO_3 and Na_2SO_4 , filtered, rotary evaporated, and dried under vacuum. The resulting solid was triturated with hexanes and filtered. The solids were further triturated with carbon tetrachloride, filtered and 25 dried under vacuum. The resulting white solid (10.2 g;

84% yield), which was analyzed by ^1H NMR spectroscopy contained 96 mol% dihydroxylated allyl ether.

5 D. Conversion of bisphenol A bis(α -dihydroxy) derivative to the bis(α -chlorohydrin) intermediate, bis(3-chloro-2-hydroxypropyl)ether of 4,4'-bisphenol A

In this part of Example 1, a 100-ml, four-necked, glass reactor equipped with a cooling condenser connected to a gas scrubber containing 40% KOH, a thermometer, a magnetic stirrer, a fritted glass gas inlet tube, and a heating lamp with thermo-controller was employed. To the reactor were added 1 g (2.66 mmol) of crude bis(α -dihydroxy) derivative of bisphenol A from Part C above, 2.5 g (18.9 mmol) of 1-methoxy-2-propanol acetate as catalyst, and 15 g of 1-methoxy 2-propanol as solvent.

15 The mixture was heated to 100-105 °C. HCl gas was slowly bubbled into the mixture for about 5.5 hours after which time GC analysis showed greater than 95% of the bis(α -dihydroxy) derivative of bisphenol A was converted into the bis(α -chlorohydrin) intermediate of bisphenol A, the structure of which was confirmed by GC comparison with standard bisphenol A bis(α -chlorohydrin) obtained from the conventional coupling of bisphenol A and epichlorohydrin.

20 The structure of the product bisphenol A bis(α -chlorohydrin), bis(3-chloro-2-hydroxypropyl)ether of 4,4'-bisphenol A, was further confirmed by HPLC/MS analysis, which is summarized in Table I below.

TABLE I. HPLC/MS analysis of bisphenol A bis(α -chlorohydrin) intermediate made from the bis(α -dihydroxy) derivative.

Peak MW	Tentative Structure	Peak Area %
376		0.2
302		0.3
418		0.1
394		6.2
320		3.6
436		1.4
408	unknown	0.1
504		0.2
412a		79
412b	isomer of 412a	0.3
450		0.8
454		0.3
484	unknown	0.1
448	unknown	0.1
362	unknown	0.1

5 E. Conversion of bisphenol A bis(α -chlorohydrin) intermediate to bisphenol A diglycidyl ether epoxy resin

In this part of Example 1, a 250-ml, four-necked, glass reactor equipped with a cooling condenser, a thermometer, a magnetic stirrer, an addition funnel for liquids, and a heating lamp with a thermo-controller was employed. Into the reactor was transferred crude bis(α -

chlorohydrin) derivative of bisphenol A prepared via a chloride substitution process and described in Experiment C2 of Example 2 of U. S. Patent Application Serial No. 60/205,366, filed May 18, 2000, (Attorney Docket No. 5 60002), incorporated herein by reference. To the reactor was also added 100 g of 1-methoxy-2-hydroxypropane as solvent. At ambient temperature, 12 g of 50% aqueous NaOH solution (0.15 mole) was added slowly to the mixture over a period of 30 minutes, after which the mixture was 10 allowed to react for about an additional 30 minutes in order to neutralize unreacted HCl dissolved in the mixture.

After removing the resulting precipitated salt by filtration, the resultant solution was transferred into 15 another 250-mL, four-necked, glass reactor equipped with a cooling condenser, a thermometer, a magnetic stirrer, an addition funnel for liquids, and a heating lamp with a thermo-controller. The solution was heated to 50-52 °C. Using the addition funnel, 12 g of 50% aqueous NaOH 20 solution (0.15 mole) was added slowly to the heated solution over a period of 60 minutes at 50-52 °C, after which time the resulting reaction mixture was allowed to react for about an additional 60 minutes at 50-52 °C. GC analysis of the resultant product indicated that greater 25 than 90% of the bis(α-chlorohydrin) derivative was converted into bisphenol A diglycidyl ether (BADGE) as identified by GC elution time comparison with an authentic commercial sample. The epoxy product was dissolved into 150 mL methyl ethyl ketone-toluene mixture (50:50, 30 volume:volume) and was washed twice with 50 mL portions of water. The organic phase was separated and concentrated

by rotary evaporation at 90-95 °C and less than 15 mmHg, yielding 13 g of epoxy resin having an epoxy content of 20.55% and an epoxy equivalent weight of 209. This reaction product was analyzed by high pressure liquid chromatography (HPLC)/mass spectrometry (MS) and the analysis of the major components is shown in Table II below.

TABLE II. HPLC/MS Analysis of Epoxidation Product of a Bisphenol A Bis(α -Chlorohydrin) Intermediate formed via a Chloride Substitution Process

Peak ID (MW)	Tentative Structure	Peak Area %
394		1.94%
358		9.32%
414a or 414b		2.06%
400		2.20%
	unknown	2.67%
376a		3.60%
376b		3.70%
340		67.90%
374	unknown	0.21%
418		0.51%

Example 2A. Conversion of phenyl allyl ether to 2,3-dihydroxypropyl ether of phenol

Phenyl allyl ether (1.0 mL) (from Aldrich) was suspended in 10 mL of H₂O and 10 mL of tert-butanol in a 100-mL round-bottom flask, and 3.32 mL of N-methyl morpholine N-oxide (50 wt% aqueous; 1.1 molar equivalents) was added to the flask. The resulting reaction mixture was stirred at room temperature, and 0.025 g of K₂OsO₄·2H₂O (2 mol%) was added to the mixture. The reaction mixture was allowed to stir for 18 hours. Then 200 mg of Na₂SO₃ and 0.2 g of diatomaceous earth were added to the mixture. The reaction mixture was stirred an additional 1 hour and then filtered. The filtrate was extracted three times with 1 volume of ethyl acetate. The resulting extracts were combined, washed twice with 1 volume of 1 N HCl, washed with one volume of water, dried over NaHCO₃ and Na₂SO₄, filtered, rotary evaporated, and dried under vacuum. The resulting white solid (1.00 g; 82% yield), which was analyzed by ¹H NMR spectroscopy, was 98% pure 2,3-dihydroxypropyl ether of phenol.

B. Preparation of 3-chloro-2-hydroxypropyl ether of phenol from the α-dihydroxy derivative of phenol

A 100-mL, four-necked, glass reactor equipped with a cooling condenser connected to a gas scrubber containing aqueous 40% KOH, a thermometer, a magnetic stirrer, a fritted glass gas dispersion tube, and a heating lamp with thermo-controller was employed. To the reactor were added 5 g (29.8 mmol) of the α-dihydroxy derivative of phenol (3-phenoxy-2,3-propanediol, purchased

from Aldrich), 8 g (60.6 mmol) 1-methoxy-2-propanol acetate as a catalyst, and 20 cc of 1-methoxy 2-propanol as solvent. The mixture was heated to 100 °C. HCl gas was slowly bubbled into the mixture for about 5 hours, after 5 which time greater than 95% of the α -dihydroxy derivative of phenol was converted. The reaction product was washed from the reactor with two 100-mL portions of methylene chloride. The portions of methylene chloride extracts containing the crude reaction product were combined and 10 washed once with 50 mL of water. The methylene chloride solution was concentrated under vacuum using rotary evaporation at 90 °C and less than 10 mmHg to yield about 4 g of colorless oil. Gas chromatography (GC) coupled with mass spectrometry (MS) analysis indicated that the major 15 product formed in greater than 95% yield is the α -chlorohydrin intermediate (3-chloro-2-hydroxypropyl ether of phenol).

C. Conversion of α -chlorohydrin intermediate of phenol to phenyl glycidyl ether

20 In this part of Example 2, a 100-mL, four-necked, glass reactor equipped with a cooling condenser, a thermometer, a magnetic stirrer, an addition funnel for liquids, and a heating lamp with a thermo-controller was employed. To the reactor was added 10 g of crude α - 25 chlorohydrin intermediate of phenol prepared as described in Part C of Example 1 of U. S. Patent Application Serial No. 60/205,366, filed May 18, 2000, (Attorney Docket No. 60002), incorporated herein by reference. The crude α -chlorohydrin intermediate prepared via a chloride 30 substitution process contains about 8.5 g of 3-chloro-2-

hydroxypropyl ether of phenol and 1.5 g of 1-methoxy-2-acetoxypropane (the amounts are based on GC area % data). To the reactor was also added 20 g of 1-methoxy-2-hydroxypropane as solvent. The resultant reaction mixture 5 was heated to 55 °C. Using the addition funnel, 5.12 g of 50% aqueous NaOH solution (0.065 mole) was added slowly to the heated mixture over a period of 15 minutes after which the mixture was allowed to react for about an additional 20 minutes. GC analysis of the resultant product 10 indicated that greater than 95% of the α -chlorohydrin intermediate was converted into phenyl glycidyl ether as identified by GC elution time comparison with an authentic sample of phenyl glycidyl ether. This reaction mixture of epoxy product was not further purified.